

**GROUNDWATER PROTECTION ISSUES AND RISKS
WITHIN
THE CROSS-VALLEY SOLE SOURCE AQUIFER AREA
FROM
PROPOSED CROSS-CASCADE PIPELINE**

Prepared for:

Cross-Valley Water District
Snohomish, Washington

Submitted by:

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EXECUTIVE SUMMARY

Golder Associates conducted a technical evaluation for Cross Valley Water District (CVWD) of the potential groundwater quality issues and risks related to the siting of the proposed Cross Cascade Pipeline. CVWD supplies groundwater to approximately 15,000 customers from a Sole Source Aquifer known as the Cross Valley Aquifer. Golder Associates reviewed the Draft Environmental Impact Statement (DEIS) for the project and the application submitted by Olympic Pipeline Company (OPC) for the project. The focus of our review was on groundwater, specifically as it related to the Cross Valley Aquifer. Golder also:

- Developed a more detailed risk assessment methodology that would more accurately predict potential consequences of a product release over the Cross Valley Aquifer;
- Conducted a review of applicable regulatory programs and guidance relating to groundwater protection;
- Summarized the hydrogeology of the Cross Valley Aquifer; and
- Summarized contaminant transport issues based on available literature.

The general conclusion of our evaluation is that the project application and subsequent DEIS have insufficiently addressed the requirements of WAC 463-42-322, which requires that "The applicant shall provide detailed descriptions of the affected natural water environment, project impacts and mitigation measures and shall demonstrate that facility construction and/or operational discharges will be compatible with and meet state water quality standards". Without substantial additional effort, Golder Associates cannot provide CVWD with a rigorous analysis of risk, potential contaminant pathways, and potential consequences to its water supply from the siting of the project.

Based on a limited analysis, that has a number of simplifying assumptions, it appears that the probability of a pipeline release that would exceed action levels at a CVWD well is about 8×10^{-4} per year. This is equivalent to a 4% chance (1 in 25) over a 50-year period. An action level is defined as one-half the MCL or advisory level for a regulated compound. Water utilities typically plan using 50-year time-frames, so it is reasonable to assume that, within the limitations of the present analysis, CVWD will experience water quality problems in one of its wells over its planning period as a result of the Cross-Cascade Pipeline. The CVWD does not have excess capacity at present, and cannot afford to lose one of its wells. Therefore, an alternative source must be assured. Wellhead Protection is a priority for the CVWD at this time, and they are actively pursuing completion of their program by July 1999.

Water districts, such as the Cross Valley Water District, depend on the proper implementation of existing regulatory programs and guidance that protects and preserves the quality of groundwater in the State of Washington. No reference was found in the DEIS or permit application to this guidance and its applicability for characterizing and managing potential risks to groundwater quality resulting from siting of the Cross-Cascade Pipeline. Existing state

guidance is generally quite specific regarding the type of information necessary and the level of detail recommended when considering projects that have the potential to contaminate groundwater.

There remains sufficient uncertainty regarding the hydrogeology of the Cross Valley Aquifer that it is not possible to determine whether the mitigations proposed by the applicant sufficiently protect the aquifer. Numerous wells exist along the pipeline alignment, but have not been identified or referenced with regard to location, stratigraphy or hydraulic properties. The geologic stratigraphy, extent and hydraulic properties of near-surface geologic strata, and water-levels/flow directions in both shallow and production zones of the Cross-Valley aquifer are not presented and may be uncertain. Geologic descriptions of the till, which is thought to provide a barrier to contaminant migration, suggest appreciable proportions of sand and gravel, which could lessen its significance as a barrier. The US Geological Survey acknowledges that areas assigned a “low” susceptibility in their regional analysis of Snohomish County could not be conclusively validated with actual data and are not valid for site-specific studies affecting specific areas.

The current and potential future use of additives or fuel oxygenates, such as MTBE, in fuels transported along the pipeline is also a concern. The environmental characteristics of these compounds may be significantly different than standard gasoline components. MTBE is significantly more soluble and recalcitrant in the environment, and appears to have health effects, though little information is available on ingested MTBE in humans. An American Petroleum Institute (1994) survey indicated that petroleum pipeline and terminal managers had noticed significant deterioration of many different types of elastomers that was associated with fuel oxygenates. Other potential additives developed in the future have an unknown risk factor.

Mitigation and contingency plans are needed that reflect the site specific and operational aspects of the CVWD service area. Given the lack of detail provided by OPC on these issues in its permit application and subsequently in the Draft Environmental Impact Statement, CVWD should request that OPC develop a spill prevention, mitigation and monitoring plan specifically for the Cross Valley Aquifer. The plan should clearly identify actions and contingencies, as well as how and when they will be implemented. OPC should work closely with CVWD on this plan, and should provide additional site-specific data in order to support the selection of specific actions. Preparation of the plan and concurrence by CVWD should be a part of any stipulated agreement with OPC.

In addition to its participation in developing a spill response plan, CVWD should initiate additional monitoring of its own wells, and possibly install additional monitoring wells to ensure that water quality standards are achieved and that a continuous water supply is assured for its customers. OPC should obtain significant guidance and oversight from CVWD in the design and implementation of a mitigation and monitoring strategy for a this regionally significant sole-source aquifer. The City of Renton is developing (at OPC's expense) a protection plan for its aquifer areas that is traversed by an OPC pipeline. This approach may be applicable to CVWD.

Although we have not conducted an analysis of potential additional external costs in the CVWD area that would result from the siting of the pipeline, it is our opinion, that the likely combined cost to CVWD and OPC for developing an adequate spill response plan (including site characterization, modeling, monitoring network design and implementation), followed by a conventional mitigation response to one large spill and the eventual installation of a treatment system at one or more CVWD wellheads, is at least at about 3 million dollars.

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1. INTRODUCTION

The Olympic Pipeline Company (OPC) proposes to construct the Cross-Cascade Pipeline through sensitive aquifer areas, including the Cross Valley Water District (CVWD) Sole Source Aquifer. A Draft Environmental Impact Statement (DEIS) was prepared for this project, based on the application for site certification prepared by the applicant and submitted to the Energy Facility Site Evaluation Council (EFSEC). Under the guidelines provided in WAC 463-42-322, the applicant must “provide detailed descriptions of the affected natural water environment, project impacts and mitigation measures and shall demonstrate that facility construction and/or operational discharges will be compatible with and meet state water quality standards”.

CVWD is concerned about the potential impacts to drinking water, and suggests that the application and DEIS have limitations that prevent the CVWD from determining the risk posed to its drinking water supply and the adequacy of possible mitigative measures. It therefore does not satisfy the guidelines provided in WAC 463-42-322.

This report has been prepared for CVWD by Golder Associates Inc. to address the following issues:

1. Develop and describe a more detailed risk assessment methodology that would allow CVWD to assess the potential for contamination of its aquifer;
2. Describe important aspects of the Cross Valley Aquifer including:
 - The status and guidance provided by existing groundwater protection programs and water supply planning.
 - The hydrogeology of the aquifer and the CVWD water supply wells, including the delineation of wellhead protection areas;
 - The number and location of private wells and water rights in the area; and
3. Describe and explain contaminant transport issues that would determine the extent, magnitude and response/treatment alternatives for aquifer contamination from the pipeline.

The report is organized into 7 sections as follows:

Section 2 describes a risk assessment methodology that would be appropriate for evaluating the potential for groundwater contamination from a pipeline release.

Section 3 describes existing groundwater protection programs and planning that are recognized by the Cross Valley Water District.

Section 4 describes the Cross Valley Aquifer and its hydrogeology, including the extent and location of private wells and water rights along

the pipeline alignment and the current delineation of wellhead protection areas in the area.

Section 5 describes technical details of contaminant transport related to gasoline and diesel products.

Section 6 provides general conclusions and recommendations related to the proposed pipeline

Section 7 contains a bibliography of relevant references

2. RISK METHODOLOGY FOR DETERMINING POTENTIAL FOR AQUIFER CONTAMINATION

The DEIS presents an assessment of the risks associated with operating the pipeline compared to the risks associated with the status quo of shipping by truck and by barge. In addition, the application mentions (but does not quantify) the risks of contaminating the Cross Valley aquifer. However, neither the application nor satisfy the element of WAC 463-42-322, that indicates the applicant must "...demonstrate that facility construction and/or operational discharges will be compatible with and meet state water quality standards". An appropriate way to demonstrate the ability of a facility to meet groundwater quality standards is through a risk assessment, which is documented in Appendix A to this report. This type of analysis should:

- Establish meaningful "performance measures" regarding the impact of the project on the groundwater resource;
- Develop an adequate framework for estimating these performance measures that includes an assessment of uncertainty/risk;
- Produce defensible results based on sufficient data supplemented with sound, logical judgment.

2.1 Performance Measures

Appropriate performance measures regarding the impact of the project on CVWD's water supply are:

- the amount of product released per year in various parts of this area as well as in the entire area;
- the amount of product which overflows the trench per year in various parts of this area as well as in the entire area;
- the amount of product per year which comes in contact with the groundwater in various parts of this area as well as in the entire area;
- the additional amount of each contaminant floating on top of the groundwater (as opposed to dissolved or mixed in with the groundwater) per year in various parts of this area as well as in the entire area;
- the peak concentration of each contaminant in groundwater each year in various parts of this area as well as in the entire area;
- the peak concentration of each contaminant in each CVWD well each year;
- the number of CVWD wells contaminated to action levels each year and over the project lifetime and their impact to CVWD, both by individual well and collectively over all wells; and
- the amount of damage each year and on the project lifetime to CVWD water supply pipes in various parts of this area as well as in the entire area.

2.2 Risk Assessment Framework

A framework for estimating these performance measures (including their uncertainties) consists of:

- identifying the various “pipeline release scenarios”, and estimating their annual probability of occurrence in various sections of the pipeline;
- identifying the various “consequence scenarios” for each release scenario, and estimating the likely performance measures for each in each section of the pipeline;
- mathematically combining the probability of each release scenario in each pipeline section with the likely performance measures for that release scenario in that pipeline section to estimate the likely performance measures (as described above), considering all possible releases and consequences.

2.3 Pipeline Release Scenarios

A limited discussion of pipeline release scenarios is provided in the application and DEIS. However the scenarios are largely narrative and do not provide a means to categorize or quantify the likelihood of occurrence for various scenarios. Pipeline release scenarios can be categorized in various ways, but consist of:

- *accidental penetration of pipeline* - Someone can accidentally penetrate the buried pipeline during excavation (e.g., by backhoe or drilling), or damage the pipeline so that it eventually becomes defective (e.g., due to stress concentrations and/or corrosion, as discussed below). For this to happen, such excavation activities must be going on and the person presumably does not know about the pipeline. The likelihood of such activities going on is a function of the land use (including any restrictions), whereas knowledge of the pipeline is primarily a function of signage (which in turn is affected by pipeline maintenance).
- *operational error leading to release* - Accidental releases can occur during pipeline maintenance (e.g., spill from an open valve) or during operation (e.g., from pressure release valve due to pipe over pressure), depending on pipeline procedures and employee training. Vandalism (e.g., intentional opening of valves) can also result in spills, depending on the degree of security provided.
- *pipe defect leading to release* - Releases can occur due to pipe defects (e.g., weld failures, joint failures, and valve fitting failures at peak operating pressure), which are a function of quality control during installation. Such defects as well as others (e.g., caused by pipe stress concentrations) can be magnified by poor pipeline construction (e.g., poor backfill), which is also a function of quality control during construction. Such defects can also be magnified and other defects created by ongoing corrosion processes, which in turn are affected by corrosion protection and environmental conditions, as well as by pipeline maintenance (i.e., catch and correct corrosion related defects before they become critical).

- *pipe break due to natural hazards* - In spite of adequate pipeline installation, subsequent natural hazards can overstress the pipeline, leading to leaks or rupture and release. For example, a pipeline which crosses a slope or slope toe can be displaced laterally by a slope failure, which in turn is caused by toe excavation or erosion and/or weakened soil due to wet conditions or earthquake. As another example, a pipeline which crosses a stream can be exposed and even become unsupported due to erosion, which in turn is due to flooding and an erosion susceptible stream bed. A pipeline can also become unsupported due to ground liquefaction (which in turn is caused by an earthquake and loose saturated granular deposits underlying h pipeline) or ground collapse (which in turn is due to karst or abandoned mines underlying the pipeline).

Each release can be characterized by a rate and duration of release, as well as by a frequency of occurrence, which may vary among release scenarios.

2.4 Pipeline Release Consequences

The consequence scenario for any release consists of:

- Released product will generally collect in the bottom of the trench, with some vaporizing, some infiltrating downward and some possibly overflowing the trench. The depth and length of product in the bottom of the trench, as well as the amount which overflows the trench, will vary with time depending on: the rate and duration of the release, the delay in starting cleanup, the schedule and effectiveness of cleanup (which involves the removal of as much product as possible from the trench), the width of the trench, the porosity and hydraulic conductivity of the trench material, and the rate at which product infiltrates downward out of the bottom of the trench.
- Product in the trench will infiltrate downward out of the trench as a function of: the depth and length of product in the trench, the hydraulic conductivity and thickness of the soils between the bottom of the trench and the groundwater below. The rate at which the product comes in contact with the groundwater is less than the rate that the product infiltrates out of the trench, due to retardation and decay (due to long travel times) in that zone which may vary among contaminants. The total amount of product which comes in contact with the groundwater will be a function of this rate in conjunction with the duration of active infiltration (IE., when product is in the trench).
- Whatever product infiltrates downward may intercept underlying CVWD pipes and cause damage, depending on whether the locations of such pipes and the zone of infiltration overlap. The extent of damage will be a function of the pipe materials (e.g., HDPE) and its exposure (IE., amount and duration) to product. If the damage is severe enough, the pipes may break and will have to be replaced immediately. In any case, the service life of the pipes will be reduced by such damage. A break of a water pipe under the product pipeline could conceivably cause erosion and

subsequent ground collapse which in turn could cause additional product pipeline releases.

- Contaminants which comes in contact with the groundwater will either dissolve in the groundwater or will float on top of the groundwater, depending on: the rate at which the contaminants come in contact with the groundwater and the maximum dissolution rate for each contaminant, which in turn depends on the solubility of the contaminant in the groundwater, the infiltration area and the groundwater flow rate at that location. Any floating contaminants will continue to dissolve in the groundwater after active infiltration has stopped. The dissolved contaminant concentration in the groundwater at this location will be the peak groundwater concentration.
- Once dissolved in the groundwater, contaminants may be transported to CVWD water wells, with different releases possibly being superimposed. The concentration of each contaminant in each well is a function of: the rate at which each contaminant is dissolved in the groundwater in each infiltration area, how much (if any) of each infiltration area is in the "well capture zone" (which in turn is a function of the groundwater flow regime and the well characteristics), contaminant transport and decay between each infiltration area and the well, and well withdrawal rates. If the concentration of any contaminant in the well exceeds specified thresholds, either the well must be closed (and the water must be replaced by another source) or the water must be treated (which is expensive and may be impractical for large volumes).

2.5 Presentation of Results

Risk assessment depends on defensible utilization of data in the framework, scenarios, and consequences under consideration. Defensible results depend on specific data and judgment relating to:

- *release scenarios* - frequency of each release scenario for each section of pipeline, and release rate (or hole size) and duration (including delay to complete cleanup) for each release scenario;
- *product* - average pipeline operating pressure, product density, and concentration of each potential contaminant;
- *pipeline trench* - average depth and width of trench, porosity and hydraulic conductivity of trench backfill material, and length of each pipeline section;
- *soil between trench and groundwater* - average thickness, hydraulic conductivity and contaminant transport properties for each section of pipeline;
- *groundwater* - average velocity and direction of groundwater flow, and mixing depth, solubility limits and contaminant transport properties, for each section of pipeline;

- *CVWD wells* - withdrawal rates and associated capture zones for each well, action levels for contaminant concentrations in well water, and impacts for each well if thresholds are exceeded.
- *CVWD pipes* - number (or location) of underlying pipe crossing in each section of pipeline, and susceptibility of pipes to damage due to exposure to infiltrating product.

A detailed quantitative risk assessment conducted as outlined above would allow CVWD to assess, manage, plan and mitigate for pipeline risk and allow equitable distribution of associated costs.

2.6 Simplified Preliminary Risk Assessment

A simplified, preliminary quantitative risk assessment was conducted, based on generic pipeline release data and on simplified groundwater flow and contaminant transport modeling (consistent with limited available site information). The results indicate a probability of about 8×10^{-4} per year, or about 0.04 (1 chance in 25) over 50 years, of exceeding action levels in at least one of CVWD's wells. An action level was defined on one-half the MCL for benzene or one-half the advisory level for MTBE. The contaminant transport modeling considered only these two compounds.

3. GROUNDWATER PROTECTION PROGRAMS

Water districts, such as the Cross Valley Water District, depend on the proper implementation of existing groundwater protection programs for the protection of the water quality to its customers. No reference was found in the DEIS or permit application to this guidance and its applicability for characterizing and managing potential risks to groundwater quality resulting from siting of the Cross-Cascade Pipeline. Existing state guidance is generally quite specific regarding the type of information necessary and the level of detail recommended when considering projects that have the potential to contaminate groundwater. Therefore, there is no indication that the project is “consistent with and [will] meet state water quality standards”.

Specific programs relevant to the siting of the Cross Cascade Pipeline include:

- Washington State Water Quality Standards Implementation Guidance
- Sole Source Aquifer Designation
- Snohomish County Groundwater Management Program
- Critical Aquifer Recharge Area (CARA) Designations
- Cross-Valley Water District Water System Planning
- Wellhead Protection Planning
- Future Supply Planning

3.1 Washington State Water Quality Standards Implementation Guidance

The Ground Water Quality Standards (Chapter 173-200 WAC) were adopted in December 1990. While the standards provide the first comprehensive approach to protecting ground water quality in Washington State, the regulation does not specifically address how it should be implemented for various types of activities. The Implementation Guidance for the Ground Water Quality Standards (April 1996 Publication No. #96-02) explains and interprets the standards providing clear direction to promote consistent statewide implementation for all activities which have a potential to degrade ground water quality. This document was developed with the assistance of an external advisory workgroup. This group was comprised of representatives from various business interests, environmental organizations, cities, counties and other state agencies. This document was also extensively reviewed by Ecology and other interested parties.

The standards are a regulatory approach to protect and preserve ground water quality. The Ground Water Quality Standards are preventative in nature and protect all waters in the saturated zone. The goal of the standards is to maintain a high quality of ground water and to protect existing and future beneficial uses through the reduction or elimination of contaminants discharged to the subsurface.

The standards affect all activities which have a potential to impact ground water quality. This guidance document implements the Ground Water Quality

Standards for all activities regulated by Ecology which have a potential to contaminate ground water. Proponents of all activities that may impact ground water quality have a legal obligation not to violate these standards regardless of whether they are directly regulated by Ecology through permits or through other regulatory mechanisms.

Water quality goals are achieved through three mechanisms:

- AKART - all known, available and reasonable methods of prevention, control and treatment. All wastes must be provided with AKART prior to entry into the state's waters, regardless of the quality of water.
- The antidegradation policy which mandates the protection of background water quality and prevents the degradation of water quality which would harm a beneficial use or violate the Ground Water Quality Standards.
- The human health and welfare based standards which include numeric and narrative standards.

Monitoring and assessment of water quality criteria are based on statistically-derived analyses of background water quality. The methods for establishing these criteria are explained in detail in Ecology's guidance.

3.2 Sole Source Aquifer Designation

The Sole Source Aquifer (SSA) Protection Program is authorized by Section 1424(e) of the Safe Drinking Water Act of 1974 (Public Law 93-523, 42 U.S.C. 300 et. seq). It states that:

"If the Administrator determines, on his own initiative or upon petition, that an area has an aquifer which is the sole or principal drinking water source for the area and which, if contaminated, would create a significant hazard to public health, he shall publish notice of that determination in the Federal Register. After the publication of any such notice, no commitment for federal financial assistance (through a grant, contract, loan guarantee, or otherwise) may be entered into for any project which the Administrator determines may contaminate such aquifer through a recharge zone so as to create a significant hazard to public health, but a commitment for federal assistance may, if authorized under another provision of law, be entered into to plan or design the project to assure that it will not so contaminate the aquifer."

The Cross-Valley Aquifer was designated as a sole source aquifer in 1987, after petition by the Cross Valley Water District. EPA defines a sole or principal source aquifer as one which supplies at least 50 percent of the drinking water consumed in the area overlying the aquifer. These areas have no alternative drinking water source(s) which could physically, legally, and economically supply all those who depend upon the aquifer for drinking water.

Proposed federal financially-assisted projects which have the potential to contaminate the designated sole source aquifer are subject to EPA review. Proposed projects that are funded entirely by state, local, or private concerns are not subject to EPA review. The Cross Cascade Pipeline is not subject to EPA review. EPA does not endorse using SSA status as the sole or determining factor in making land use decisions that may impact ground water quality. However, it does recommend that site-specific hydrogeological assessments be considered along with other factors such as project design, construction practices, and long-term management of the site.

3.3 Snohomish County Groundwater Management Program

The Snohomish County Groundwater Management Plan (GWMP) was developed according to guidelines promulgated by the Washington Department of Ecology through WAC 173-100. The plan was developed by the Snohomish County Groundwater Advisory Committee (GWAC), which was formed in 1993 with about 35 members representing local (cities, towns, businesses, and citizens), tribal, county, and state interests. Cross Valley Water District serves as Chair of the GWAC. Figure 3-1 shows the location of the GWMP and the CVWD sole serve aquifer.

Since 1993, the GWAC has met monthly to discuss groundwater issues and concerns, and in particular, to develop discussion papers on specific potential impacts to both groundwater quantity and groundwater quality. The GWMP is currently undergoing the concurrence process, whereby it will be formally accepted by the Department of Ecology and Snohomish County. A final document is currently in preparation.

The US Geological Survey (Thomas and Others, 1996) developed an aquifer sensitivity ranking method for the Snohomish County Groundwater Management Area that considered surficial geology, depth to groundwater, and groundwater recharge rate. The entire GWMA was classified according to three classes, low, medium, and high. The distinction between vulnerability and sensitivity is important. The US EPA divides the potential for groundwater contamination into two parts : sensitivity and vulnerability. Sensitivity is the relative ease with which contaminants applied at or near the surface can enter the groundwater system. Sensitivity relates primarily to physical characteristics. Vulnerability includes both sensitivity and the human activities which determine the source quantity, and type of contaminants. An area can have a high sensitivity but a low vulnerability if there are no contaminant sources present. Conversely, an area can have a low sensitivity but a high vulnerability if large amounts of a contaminant are applied to an area.

Figure 3-2 show the sensitivity rating prepared by the USGS. The USGS study evaluated sensitivity only, using a methodology similar to the DRASTIC method developed for the USWEPA (Aller and others, 1985). The sensitivity ratings could not be conclusively validated with actual data, though an attempt to relate nitrate and dissolved oxygen concentrations to sensitivity ratings was

attempted. Therefore, the sensitivity ratings have many limitations, which are acknowledged by the USGS, including:

- Sensitivity values are not absolute, and do not indicate specific probabilities or rates of contaminant movement;
- The ratings are regional in scale, and not valid for site-specific studies. They are applicable for area larger than about 1 square mile;
- The accuracy of the ratings is unknown;
- Differences in contaminant behavior are not considered.;
- Temporal changes in sensitivity (i.e. winter versus summer) are not considered; and
- Soil characteristics are not considered.

For a specific project such as the Cross Cascade Pipeline, the use of the USGS sensitivity ratings is insufficient for assessing the vulnerability to contamination.

3.4 Critical Aquifer Recharge Area (CARA) Designations

In 1990, the Washington State Legislature adopted the Growth Management Act, Engrossed Substitute House Bill 2929, now codified as Chapter 36.70A RCW (Revised Code of Washington). This statute combined with that of Article 11 of the Washington State Constitution mandates that local jurisdictions adopt ordinances that classify, designate, and regulate land use in order to protect critical areas. Critical areas are defined as wetlands, frequently flooded areas, aquifer recharge areas, geologically hazardous areas, and those areas necessary for fish and wildlife conservation. Critical Aquifer Recharge Area (CARA) ordinances are a means to protect ground water quality and ensure that sufficient aquifer recharge occurs to support ground water's use as a potable water source. Snohomish County is currently preparing to designate CARA's and develop ordinances for protection. Appendix B contains Ecology's CARA Guidance (without appendices).

3.4.1 Underlying Concepts

The Department of Ecology has created a guidance document for developing CARA's which is based on several basic underlying concepts relevant to siting of the CCP:

- All ground water is vulnerable to contamination; however, hydrogeologic conditions in some areas create a greater potential to convey

contamination from points of recharge (locations where ground water is replenished) to the point of use. To protect ground water in these sensitive areas, it is necessary to first determine where such areas exist using technically sound but realistic methodologies.

- A CARA delineation is best based upon the known or suspected vulnerability of aquifer(s) within a designated area. The determination of an aquifer's vulnerability is based on aquifer susceptibility combined with a contaminant's ability to enter and move within the aquifer media. The vulnerability determination is based upon known and inferred conditions developed from limited field data. In many cases, it will be difficult to determine known conditions. In these situations, it is necessary to adopt a conservative approach as it applies to contaminant migration. In this case, it is assumed that contaminants will not be either retarded or degraded as they pass from the surface to the underlying aquifer(s).
- Previous geologic and/or hydrogeologic characterizations contain information valuable to determining where a CARA may exist. All readily available information pertaining to designations of aquifer susceptibility or aquifer vulnerability should be used in order to complete an initial determination.
- Previous water quality information, collected as part of a study or survey, which indicates degraded ground water or negative changes in ground water quality, should be considered as an indication of susceptible ground water.
- To the greatest extent possible, ordinances resulting from the requirements of the Growth Management Act should address the requirements of the Water Pollution Control Act, the Water Resource Act of 1971, Ground Water Quality Standards, and Washington State's antidegradation policy.

Future development of CARA's may make the pipeline a non-conforming use under a Critical Aquifer Recharge Area Ordinance, as required by the Growth Management Act. Nonconforming uses ordinarily may not be terminated immediately, but the local jurisdiction can phase them out over a reasonable period of time. Ecology recommends that local jurisdictions use their police power authority to phase out nonconforming activities and facilities that threaten contamination of the ground water source(s).

Ecology's CARA Guidance suggests provisions whereby a proposed facility, wishing to locate or expand over an area previously designated as susceptible, conduct a site-specific evaluation to ascertain whether mitigative measures can be put in place that would allow approval of the facility or activity. The specific site evaluation would describe the elements necessary to characterize the site, the activity, and the potential impacts of the project, would contribute to the existing data on which the current CARA boundaries and classifications are based, and may lead to modification in the future.

3.4.2 Recommended Site Evaluations

When considering the issuance of a “permit to locate over a designated CARA”, Ecology recommends that the following information be compiled by the owner or operator of the project and evaluated by the local jurisdiction:

1. Current environmental conditions.
2. Constituents released into the environment by the activity.
3. The potential to degrade the environment by the activity.

This has not been conducted within the Cross-Valley Sole Source Aquifer. The following section details the information recommended by Ecology that should be compiled for the Site Evaluation Report and additional requirements that may be necessary depending upon the activity and the complexity of the site.

Class A Site Evaluation

1. Permeability of the unsaturated zone.
2. Location of nearby sensitive areas (i.e. wellhead protection areas)
3. Ground water depth and flow direction.
4. Location, construction, and use of existing wells (1/4 mi.).
5. Site map at 1:2,400 (1 inch to 2,000 feet) scale.
6. Activity characterization.
7. Best Management Practices.
8. Contingency Plan.

Class B Site Evaluation

These evaluation reports should contain all the information included as part of a Class A

Site Evaluation Report along with the following additions:

1. Background water quality compiled over at least a one year period.
2. Contaminant transport modeling based on potential releases to ground water.
3. Modeling of ground water withdrawal effects.
4. Geologic and hydrogeologic characteristics.
5. Ground water monitoring plan provisions.

Specific recommended elements of these investigations are summarized below. Very little of this information has been incorporated into the assessment of possible impacts from the Cross- Cascade Pipeline.

1. The geology of a site should be characterized through the interpretation of well logs, geologic maps, and cross sections. Cross sections can be constructed from information contained in drillers’ logs and geological reports. This information may be required if the geology is complex or if there are multiple aquifer systems. Structural features should be delineated, such as faults, fractures, fissures, impermeable boundaries or other

subsurface features that might provide preferential pathways for contaminant migration.

2. The geomorphology of the area should be described including the topography and drainage patterns. The soils on the site should be identified and described by type, horizontal and vertical extent, infiltration rate, organic carbon content, and mineral content.
3. The lithology of the uppermost aquifer and the overlying units in the unsaturated zone should be defined in terms of thickness, permeability, and aerobic or anaerobic conditions. These parameters will be used to identify contaminant movement and behavior prior to reaching ground water.
4. Additional hydrogeologic parameters should be identified, such as ground water velocity, transmissivity, storage coefficient, hydraulic conductivity, porosity, and dispersivity. These hydrogeologic parameters are necessary to characterize the rate of contaminant movement in the aquifer and to accurately assess the area potentially impacted by the facility's activities. Ground water flow conditions such as the flow rates, volumes, and directions should be identified. Any available hydrographs or equipotential maps should also be included.

5. Precipitation, evaporation, and evapotranspiration rates should be identified for the area.
6. Contaminant fate and transport, including probable migration pathways, should also be included.
7. The location of previously defined sensitive areas should be included as part of both a Class A and Class B site evaluation. The purpose of including these areas is to make both the jurisdiction and the applicant aware of areas requiring protection beyond that which may be afforded in the CARA. Generally, sensitive areas extending outward in a three-mile radius from the proposed activity should be considered as adequate.
8. Depth to ground water below the land surface should also be defined by taking static water levels from a reasonable number of wells for a period of time sufficient to characterize ground water elevation trends. Water level elevations should be monitored on a monthly or quarterly basis to determine seasonal variations in ground water flow.
9. Seasonal water level fluctuations in the uppermost aquifer may occur and should be taken into account. A ground water potentiometric map illustrating ground water flow directions should be included for *all aquifers* that have a potential to be contaminated by the discharge. Data allowing for the determination of flow direction and ground water gradient should include the locations of wells, dates of measurements, locations of measuring points relative to the land surface elevation, depth to water, time since the wells were last pumped, other area wells which were pumping during the measurement, and any available construction data such as total depth and screened interval. A contour map should be drawn from the resulting information. Ground water divides should also be noted.
10. Background water quality is defined as the quality of ground water that is representative of the conditions without the impacts of the proposed activity or facility. Because individual ground water samples are only representative of ground water quality at a specific time and location, they (by themselves) cannot provide an adequate assessment of water quality over a period of time. To satisfy the requirement for a background water quality determination, at least eight samples collected over a one-year period with no more than one sample collected during any month in a single calendar year, upgradient from the activity or facility must be obtained. Background water quality can then be determined using methodologies outlined in Ecology publication # 96-02, *Implementation Guidance for the Ground Water Quality Standards*.
11. All wells within a one-quarter mile radius of the activity or discharge point should be located on a 1:24,000 scale map. This includes domestic, irrigation, monitor, and public drinking water supply wells. The level of detail will depend on the complexity of the activity and the hydrogeology of the site. Available information on the well use and construction should be included for all contiguous wells and other representative wells within the

one-quarter mile radius. Construction information should consist of well depth, static water level, screened interval, and geologic well logs. This information will be used for determining geologic characteristics of the subsurface, developing potentiometric maps, assessing the adequacy of wells for sample collection, and evaluating potential impacts to area wells in the event of environmental contamination.

12. Details of any proposed monitor wells should be submitted to Ecology to assure they are located and designed properly prior to installation.
13. Contaminant Modeling. The area potentially affected by pollutant migration should be described. This is the area that will be affected chemically, physically or biologically as a result of the activity. The area impacted should take into account advection, dispersion, and diffusion of contaminants in ground water. The size of the area will depend upon the effluent quality, the aquifer characteristics, and the rate of assimilation. The applicant can demonstrate this by using a simple mixing equation or a computer model.
14. The location of the facility should be illustrated on a 1:2400 scale map, plus an enlarged map of the facility. The facility site boundary and land ownership or uses of the adjacent property should also be delineated on this map. Additionally, a site plan should be submitted that is drawn to approximate scale. The site map should include the following: property lines, buildings, structures, locations of wells, locations of other underground conveyance systems (i.e., underground storage tanks, septic systems, water lines, gaslines, etc.), location of geologic borings, the discharge point location, topography, plus any other relevant information.
15. The Site Evaluation Report should include a spill plan or a contingency plan depending upon the individual circumstances. A contingency plan should be prepared which describes the specific actions to be taken if a violation occurs. A contingency plan should identify all the equipment and structural features that could potentially fail, resulting in immediate public health or environmental impacts. A plan should be developed that describes the action(s) necessary to remedy impacts of such an event in a timely manner. This includes an outline of the procedures for controlling the release, the proposed methods for evaluating the extent of contamination, and alternatives for remediation. An emergency response coordinator should also be identified. This person is responsible for notifying proper authorities and implementing the contingency plan in the event of a release to the environment that may cause imminent or substantial endangerment to public health or the environment.

3.5 Wellhead Protection Planning

Wellhead protection programs in the State of Washington are required of all Group A public water systems relying on groundwater. The following minimum

requirements are mandated by the State of Washington wellhead protection program:

- A susceptibility assessment for each groundwater source;
- Delineation of wellhead protection areas for each source;
- An inventory of all actual and potential groundwater contamination sources that are located within each wellhead protection area which must be updated every two years;
- Documentation of the purveyor's notification to all owners/operators of actual and potential contamination sources that are located within a wellhead protection area;
- Documentation of the purveyor's notification to regulatory agencies and local governments of the boundaries of the wellhead protection areas and the results of the contaminant source inventory;
- A contingency plan to ensure that water system customers have an adequate water supply in the event that contamination causes temporary or permanent loss of the principal water source; and
- Documentation of coordination with local emergency spill response teams regarding the locations of the wellhead protection areas and the water supply sources, and the results of the contaminant source inventory and the contingency plan.

The Cross Valley Water District (CVWD) is developing a wellhead protection program in order to prevent contamination of their groundwater supply. To date, they have completed two components of the wellhead protection program: 1) preliminary delineation of wellhead protection areas using a groundwater flow model for each of the CVWD wells; and 2) completion of a contaminant source inventory focused within the wellhead protection areas. Section 4.12 summarizes the results of the preliminary wellhead protection area delineations.

The CVWD is currently evaluating a proposal to complete the Wellhead Protection Plan. This work may involve collection of additional hydraulic data and revision of the model to more accurately reflect observed conditions. It will also address the outstanding DOH requirements for wellhead protection planning. This work is expected to be completed by July 1999. In the interim, it is believed that the preliminary Wellhead Protection Areas sufficiently demonstrate the sensitivity of the wellfield area to contamination, and are consistent with WDOH guidelines for establishing Wellhead Protection Areas.

The Cross Cascade Pipeline would become by far the largest volume contaminant source within the CVWD Wellhead Protection Area.

3.6 Future Supply Planning

Cross Valley Water District, Northshore Utility District, and Woodinville Water District are actively involved in the identification of future water supplies for

their individual water districts and the Puget Sound region in general. There is significant pressure on water utilities to identify new sources that are both adequate for growing demands and environmentally sound. The development of new groundwater supplies has been severely curtailed in recent years as a result of environmental concerns regarding the possible reduction in streamflows from the development of groundwater supplies. For this reason, existing groundwater supplies are extremely valuable, as the opportunity to develop new groundwater supplies will only continue to diminish. The Cross Cascade Pipeline crosses two major aquifer systems (Cross Valley Aquifer and Snoqualmie Aquifer) that can support water supply demands both now and into the future. Both the Cross Valley Aquifer and the Snoqualmie Aquifer near North Bend have the potential to become more important to the region as a water supply:

1. The Snoqualmie Aquifer has the potential to provide up to 40 million gallons per day of supply.
2. The Cross Valley Aquifer currently supplies 5 million gallons per day, and may have a capacity for up to 10 million gallons per day.
3. Artificial Storage and Recovery (ASR) can further increase the potential supply, particularly from the Cross-Valley Aquifer. A preliminary assessment of ASR in the Cross-Valley Aquifer was conducted by Northshore Utility District, and the concept remains viable, potentially doubling the peak summer capacity of the aquifer.

4. CROSS-VALLEY AQUIFER

4.1 Cross Valley Water District Service Area and Location

The Cross Valley Water District provides service to an area of approximately 25 square miles in southern Snohomish County between the communities of Woodinville, Snohomish, and Monroe (Figure 4-1). CVWD provides water supply to residents, businesses, and public schools and currently serves a population of approximately 14,100. Population growth models predict an increase to 20,400 customers by the year 2000. In addition to the CVWD customers, there are also about 11,000 citizens in the area that rely on groundwater from the local aquifer through the use of private wells. This population is also increasing and is predicted to reach 16,000 by the year 2000. The total population within the CVWD service area that relies on groundwater is therefore expected to reach 36,400 by the year 2000. Maintaining a high-quality groundwater resource for this population is critical to the region.

4.2 CVWD Water Supply System

About 89% of the water supplied by the CVWD is from groundwater sources, while the remaining 11% is surface water that is purchased from the City of Everett. The surface water that is purchased from Everett is used to supply customers that are located within the northern part of the service area near the City of Snohomish. Customers located throughout the remainder of the service area receive groundwater that is pumped from wells located in the southern part of the service area.

A summary of the CVWD wells, which includes the depth and completion interval for each well, is provided in Table 4-1. CVWD owns 11 water supply wells which range in depth from 168 to 437 feet. Only 10 of the wells are used or planned for use in the water system. All of these wells with the exception of the Woodlane Well were installed by CVWD. The Woodlane Well was recently acquired when CVWD purchased a small private water system. Of the other wells, Well No. 2 is not in service, Well No. 4 was drilled and abandoned because of insufficient water production rates, and Well No. 10 is a newly drilled well that will be put into service in the near future. All of the wells withdraw groundwater from the Cross Valley Aquifer, which is continuous throughout the region.

Data are also provided in Table 4-1 for two water supply wells owned by the Woodinville Water District. The wells, identified as PW-1 and PW-2, are new installations and were recently denied water rights, thus, they cannot be used at present. However, it is likely that at sometime in the future the wells will be used on a permanent basis or for emergency purposes. Both wells withdraw groundwater from the same aquifer as the CVWD wells.

A summary of the production rates from the CVWD wells is provided in Table 4-2. Recent production from the CVWD wells has been estimated based on the metered withdrawals from the wells during 1993 and 1994 (data were provided

by CVWD). The average annual withdrawal for 1993 and 1994 was 484.5 million gallons (Mgal), which equates to an average day demand of 1.33 mgd (million gallons per day). Roughly three-quarters of the groundwater withdrawals were supplied from Well Nos. 5, 6, and 9. The estimated maximum and present yields from the CVWD wells are also provided in Table 4-2. As shown, Well Nos. 9 and 10 have the highest yields of 980 gpm and 700 gpm, respectively. Well Nos. 5, 6, 7, and 8 each provide 450 gpm. These six wells make up the core of the CVWD groundwater sources. Additional but smaller yields are obtained from Well Nos. 1, 3, and 7A. Based on comparison between the maximum and present yields, it is shown that some production rates have declined since the wells were constructed.

The projected supply requirements to the year 2008 (5.83 MGD) exceeds the current capacity of the CVWD wells. This loss on one or more wells is a potentially serious consequence.

4.3 Summary of Data

This section summarizes the information sources that are available to develop a hydrogeological conceptual model. These information sources include the following:

Mapping data are available from the following sources:

- US Geological Survey (USGS) 7.5-minute topographic maps;
- USGS surface geological maps for the Bothell (Minard 1985), Kirkland (Minard 1983), Maltby (Minard 1985), and Redmond (Minard and Booth 1988) Quadrangles;
- Map of the CVWD distribution system and water supply well locations (CVWD undated);
- ARC/INFO format digital mapping data from the USGS including coverages for: surface geology; areal extent of geologic units; geological unit top elevations; and groundwater recharge rate;
- ARC/INFO format digital mapping data from Snohomish County-GIS for land use zoning based on the recent Growth Management Act Comprehensive Plan (Snohomish County 1995); and
- Hydrologic features and roadways in ARC/INFO compatible digital format from the Washington State Department of Transportation.

Regional Hydrogeology Geological and hydrogeological data pertaining to the general region of the Cross Valley Water District are available from a variety of sources. As discussed under mapping, 7.5-minute maps of surface geology were available from the USGS in addition to ARC/INFO GIS coverages. Work completed by Newcomb (1952) and by Liesch et al. (1963) provided detailed characterizations of the geology and the groundwater resources of Snohomish County and of northwestern King County, respectively. Additional detailed geological information was obtained from the Snohomish County Groundwater

Management Program Phase One Study report prepared by the USGS (Thomas and others, 1996).

WDOE Well Logs Hydrogeological data are available from well logs on file at the Washington State Department of Ecology (WDOE) in Bellevue, WA. Existing well logs on file are available for the following areas:

- Township 28 North, Range 5 East, Sections: 31 - 36;
- Township 27 North, Range 5 East, Sections: 1 - 36;
- Township 27 North, Range 6 East, Sections: 6, 7, 17 - 22, 26 - 35;
- Township 26 North, Range 5 East, Sections: 1 - 18; and
- Township 26 North, Range 6 East, Sections: 2 - 11, 15 - 18.

Several hundred well logs were identified at WDOE. From these, a number of well logs are included in Appendix B, as being within approximately 1 mile of the proposed pipeline alignment.

CVWD Reports Individual well reports prepared for each of the CVWD wells were reviewed for geological and aquifer-property data (Robinson and Noble 1973 to 1990 and Harstad Associates Inc. 1971). Other useful reports prepared by CVWD included an earlier groundwater resources study (Robinson and Noble 1983) and a recent update (Robinson and Noble 1994). These reports contained information on geologic profiles, depth to water, and in many cases, detailed aquifer testing results.

Woodinville Water District Well Reports Additional hydrogeological data are available from well construction and testing reports of two wells newly installed by the Woodinville Water District (Hart Crowser 1994a, 1994b). Both wells withdraw groundwater from the Cross Valley Aquifer and the reports included data on the geologic profile, depth to water, and aquifer properties.

Geophysical Data and Interpretations Geophysical data (time-domain electromagnetic data) were available from several surveys conducted in the (Little) Bear Creek drainage by the Northshore Utility District (Golder Associates 1994). These surveys provided electrical resistivity profiles and interpretations of aquifer depth and aquifer properties.

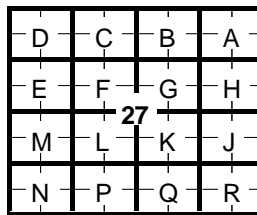
Hydrology and Climate Data Streamflow data for (Little) Bear Creek are available from USGS gage 12125500 located in Woodinville, WA. Precipitation data from stations located near Bothell, Snohomish, and Monroe, WA are available from a summary published by Washington State University (1966). This publication also contained estimates of both potential and actual annual evapotranspiration at a climate station located near the project area.

4.4 Private Wells

A records search of wells within the Cross Valley Water District Service Area was conducted at the Department of Ecology's Northwest Regional Office in Bellevue, Washington. To meet the Washington Department of Ecology

(WDOE) CARA Guidance, the search area included a 3-mile buffer zone to the north and south of the proposed pipeline alignment.

Wells were located based on the “quarter-quarter” township and range location provided on the well logs. This coordinate system provides an accuracy of +/- 0.25 miles, assuming that the well log indicates the proper quarter section. It is not uncommon to encounter location errors of up to 0.5 miles using well log coordinates because of potential confusion or reversal of “quarter-quarter” descriptions. Plate 1 shows the approximate location of wells within the CVWD service area and includes designation for each well. This well designation, for example “27K02” describes the township (27), the “quarter-quarter” section (K) and the well specific identification number (02). The diagram below illustrates the “quarter-quarter” section location method. With reference to the diagram, well “27K02” would be located in the center of the K quarter-quarter section.



A total of 224 wells were located as a result of the search and are shown on Plate 1. The number of wells within each of the pipeline buffers are summarized as follows:

Distance from alignment	No. of Wells
0.00 - 0.25 Mile	19
0.25 - 0.50 Mile	31
0.50 - 1.00 Mile	22
1.00 - 3.00 Mile	152

4.4.1 Cross Valley Water District Wells

The Cross Valley Water District owns 11 water supply wells which range in depth from 168 to 437 feet. Ten of these wells are used or planned for use in the water system. All of these wells with the exception of the Woodland Well were installed by CVWD. Of the other wells, Well No. 2 is not in service and Well No. 4 was drilled and abandoned because of insufficient water production rates. All these wells withdraw groundwater from the Cross Valley Aquifer. Table 5.1 summarizes the completion details for the CVWD wells. Table 5.2 summarizes CVWD well production and aquifer hydraulic properties.

The locations of the CVWD wells are shown on Plate 1. The well designations and approximate distances from the pipeline alignment for the wells are as follows:

CVWD Well ID	Well Designation	Approx. Distance from Alignment (miles)	Approx. Distance from Alignment (ft)
CVWD Well # 1	24M04	0.28 N	1,500 N
CVWD Well # 3	25G02	0.57 S	3,000 S
CVWD Well # 5	24F04	0.38 N	2,000 N
CVWD Well # 6	24F03	0.38 N	2,000 N
CVWD Well # 7	35M01	1.51 S	8,000 S
CVWD Well # 7a	35M02	151 S	8,000 S
CVWD Well # 8	25G01	0.57 S	3,000 S
CVWD Well # 9	24M03	0.25 N	1,500 N
WoodLane Well	35A01	1.32 S	7,000 S

The following wells were physically located on February 4, 1999:

CVWD Well #5 and #6 - both wells are located within locked and fenced well houses and are accessed via a gravel road running in an easterly direction from 87th Avenue SE just north of 206th Street. During the site visit on February 4, 1999, pump maintenance was being completed on Well # 6. This well has a flow through adsorption system to reduce iron and manganese in drinking water. Illustrations of the Well # 6 pump house and adsorption system are included in Appendix E as Photo #s 1, 2 and 3. An illustration of the Well #5 pump house is presented in Appendix E as Photo # 4. The wells are located topographically upgradient of the high power transmission lines along which the proposed pipeline is to be aligned. A stormwater infiltration system, which appears to be conveying stormwater in a westerly direction from Broadway Street was noted approximately 500 ft southeast of the wells. Photographs illustrating the stormwater system are presented in Appendix E as Photo #s 5 and 6.

CVWD Well #9 and #1 - are surrounded by a 10 foot high wire fence. They are located at the northern end of 86th Avenue SE, north of 206th Street. The southern boundary of the fenced area can be seen from the intersection of the pipeline alignment and Date Street (the southern continuation of 86th Avenue SE). Photo #7 in Appendix E presents a view looking from the pipeline alignment northwards towards Wells #9 and #1 (located in the trees at the far end of the road). Photo #s 8 and 9 illustrate an easterly facing and westerly facing view respectively of the alignment from this same vantage point. CVWD Wells #9 and #1 are located topographically upgradient of the alignment.

CVWD Well #8 and #3 - are also surrounded by a 10 foot high wire fence. They are located on 97th Avenue SE, just north off Paradise Lake Road. The pipeline alignment was not in view from this location.

4.4.2 Private Wells

The remaining 215 wells located on Plate 1 (224 minus the 9 CVWD wells) are private wells used mainly for domestic water supply and irrigation. However, this does not necessarily represent all wells in the project area. During the

February 4, 1999, site visit, further investigation was made of wells at the Echo Falls Country Club (along the proposed alignment) where a number of relatively deep irrigation wells had been identified but were not on file with WDOE. The following provides a description of the 14 tee wells.

Echo Falls County Club 14 Tee Wells - are two of a number of wells used in the summer to irrigate the Falls Golf Course which is located just south of Highway 522, between Echo Lake Road and 129th Avenue SE. The wells are located approximately 100 ft south of the alignment and are illustrated in Appendix E Photo #s 10 and 11. Based on communication with Rich Jahnke, the Superintendent of the Echo Falls Country Club, there are up to 6 wells located on the golf course. Drillers' logs for three of these wells were on file at the maintenance shop and were copied for inclusion Plate 1. Two of these logs were not found in the WDOE file search. Since these wells are easily accessible and are located at close proximity to the alignment, matching the available logs to the wells would be useful along with field water level measurements to better characterize the subsurface hydrogeology in this vicinity.

4.5 Water Rights

The Washington Department of Ecology water rights database was queried for the number and quantity of existing water rights and applications in proximity to the pipeline alignment. Similar to well log information, the accuracy of the information is dependent on the scale of the query and the original information entered on to the water rights application and permit forms.

The table below lists the number and volume of water rights within a one mile distance from the alignment. Note that the information obtained from the database is on a section by section basis and that water rights within a section are not accurately located. Total numbers of water rights, both surface water and groundwater, are summarized as follows:

Twtnshp, Rng, Section	Rights/ Application s	Numbe r	Qa Rights/Applicati ons (acre feet / yr.)	Qi Rights/Applicatio ns (gw-gpm) (sw-cfs)
T27N, R5E, 20	surface water	0		
	groundwater	1	25	300
T27N, R5E, 21	surface water	0		
	groundwater	1	1	7.5
T27N, R5E, 22	surface water	5	508.25	0.72
	groundwater	3	64.25	120
T27N, R5E, 23	surface water	0		
	groundwater	2	58.4	85
T27N, R5E, 24	surface water	0		

Twنشp, Rng, Section	Rights/ Application s	Numbe r	Qa Rights/Applicati ons (acre feet / yr.)	Qi Rights/Applicatio ns (gw-gpm) (sw-cfs)
	groundwater	9	3763	3355
T27N, R5E, 25	surface water	0		
	groundwater	6	1022.2	1025
T27N, R5E, 26	surface water	0		
	groundwater	1	1	10
T27N, R5E, 27	surface water	3	12.2	0.06
	groundwater	2	26	95
T27N, R5E, 28	surface water	1	1	0.02
	groundwater	1	2	15
T27N, R5E, 29	surface water	7	1658	2.29
	groundwater	1	24	15
T27N, R6E, 18	surface water	5	174.8	0.26
	groundwater	1	5.7	30
T27N, R6E, 19	surface water	0		
	groundwater	1	4	40
T27N, R6E, 20	surface water	0		
	groundwater	0		
T27N, R6E, 21	surface water	3	87.3	0.16
	groundwater	1	4.5	14
T27N, R6E, 22	surface water	2	362.2	0.5
	groundwater	2	27.5	73
T27N, R6E, 27	surface water	2	92.4	0.2
	groundwater	2	9	45
T27N, R6E, 28	surface water	1	1	0.02
	groundwater	1	2	20
T27N, R6E, 29	surface water	0		
	groundwater	0		
T27N, R6E, 30	surface water	0		
	groundwater	0		
TOTAL	surface water	29	2897.15 acre-feet /yr.	4.23 cfs
	groundwater	35	5039.55 acre-feet /yr.	5249.5 gpm

Within the one mile buffer of the pipeline alignment, the Cross Valley Water District owns the majority of the water rights in terms of volume. Based on the database query, the CVWD has groundwater rights for an annual withdrawal (Qa) of 4,642 acre-feet (92% of the total Qa) and an instantaneous withdrawal (Qi) of 4,060 gallons per minute (77% of the total Qi). Private groundwater rights account for the balance, i.e. groundwater rights for an annual withdrawal (Qa) of up to 397.55 acre-feet (8% of the total Qa), and an instantaneous withdrawal (Qi) of 1,189.5 gallons per minute (23% of the total Qi). According to the database, the surface water rights detailed above are all privately owned.

4.6 Hydrogeologic Units

A groundwater system consists of one or more hydrogeologic units that individually can be characterized as either an aquifer or as a confining layer. An aquifer is a saturated permeable geologic unit that is capable of transmitting a usable quantity of water. A confining layer is a geologic unit that restricts the movement of groundwater. Plate 1 shows the surficial geology of the project area. The surficial geology corresponds to units encountered both at and below the ground surface in wells. These units are generalized categorizations of the actual composition of the materials. Seven principal hydrogeologic units are present within the project area.

Alluvium (Qal) is the youngest hydrogeologic unit. This unit is present along several stream channels and typically consists of sand and gravel with some finer-grained materials including organic deposits. The alluvium does not represent a viable aquifer because it covers a relatively small area and is often unsaturated. In other parts of Snohomish County the alluvium is an aquifer, such as in the Snohomish River Valley.

Vashon recessional outwash (Qvr) is the second hydrogeologic unit in the vertical sequence. This unit was deposited by meltwater as a continental glacier retreated from the Puget Sound regions approximately 13,000 to 15,000 years ago. It is comprised of sediments ranging from fine-grained silt to coarse-grained sand and gravel. In the project area, it mostly occurs in stream drainages. The potential of this unit as an aquifer is limited by a relatively thin saturated thickness.

Vashon till (Qvt) is a confining layer that occurs extensively in the project area. As shown on Plate 1, much of the land surface consists of Vashon till. Commonly referred to as hardpan, the till is a poorly sorted mixture of clay to gravel sized particles deposited directly from a continental glacier and consequently compacted by the thick ice pack. The description of the till in area well logs is quite variable

Vashon advance outwash (Qva) is present below the till and locally at land surface. This unit was deposited by meltwater streams emanating from the advancing continental glacier. The Cross Valley Aquifer occurs in the Vashon advance outwash wherever it is saturated by groundwater. In this report, Vashon advance outwash and Cross Valley Aquifer are used somewhat

interchangeably. The Vashon advance outwash consists of a number of layers ranging in texture from sandy silt to sandy gravel. The coarse-grained layers consisting of sand and gravel are tapped by productive water wells. All of the CVWD wells withdraw groundwater from this formation, as do the new Woodinville Water District wells.

Transitional beds (Qtb) are a confining unit that underlies the Vashon advance outwash. Deposition of this unit is believed to occur during an inter-glacial period when continental glaciers had retreated from the Puget Sound area. Clay and silt strata are characteristic of the transitional beds.

Undifferentiated sediments (Qu) occur below the transitional beds. This unit has been classified as an aquifer unit by the USGS (Thomas and others, 1996). It is not known if this unit is of aquifer quality in the project area.

Bedrock (Tb) consists of a variety of sedimentary rocks, which are present in outcrop along the northeast portion of the project area.

4.7 Aquifer Extent

The primary aquifer in the project area has been referred to for years as the Cross Valley Aquifer. This aquifer exists within the Vashon advance outwash. Wherever the Vashon advance outwash is saturated, it forms the Cross Valley Aquifer.

The Vashon advance outwash ranges in thickness from about 50 feet to over 200 feet within the project area. The greatest thicknesses occur under the Plateau areas, which are capped by till. The Vashon advance outwash is terminated abruptly at bluffs which define the edges of the Plateau areas. These bluffs occur in the northern, eastern, and parts of the western boundary of the project area.

The top elevation of the Vashon Advance Outwash represents the top of the Cross Valley Aquifer where the Vashon advance outwash is fully saturated and the aquifer is technically confined by the overlying Vashon till. However, over most of the project area the Cross Valley Aquifer is unconfined and therefore the top of the aquifer is determined by the water table, which occurs at an elevation below the top of the Vashon advance outwash.

Using well logs, the top elevation is determined where "hardpan", till, or gray silty sand transitions vertically downward to brown sand and gravel mixtures. The Vashon advance outwash top elevation ranges from about 150 feet to at least 468 feet above mean sea level, as estimated from the existing data. The top elevation generally mirrors the surface topography. It is highest in the Plateau areas and lowest in the stream valleys where it has been eroded.

The bottom elevation of the Vashon advance outwash in the project area is not well known, as few data are available to define the bottom elevation. In well logs, the bottom elevation of the Vashon advance outwash is marked by a

transition vertically downward from sand and gravel to silt and clay. On a surface geological map, the bottom elevation of the Vashon advance outwash is shown by the mapped contact with the underlying transitional beds and the associated land surface elevation.

The base of the Vashon advance outwash is estimated to slope gently from east to west. The highest elevation occurs in the Mount Forest area, where the bottom elevation reaches 300 feet above mean sea level. To the west at Woodinville, the bottom elevation drops to less than 100 feet above mean sea level.

4.8 Geologic Cross-Section

Figure 4-2 presents a detailed west-east geologic cross-section drawn along the proposed pipeline alignment from A to A' as indicated on Plate 1. The cross-section was constructed using well log information for wells located within approximately 1/2 mile north and south of the pipeline alignment. The logs used to build the cross-section were chosen based on the quality of the information presented and the geologic information projected directly onto the section line. A compilation of these logs are included in Appendix C.

As indicated on Figure 4-2, the stratigraphy across the alignment is very varied. Correlation between the hydrogeologic units as described in Section 4.6 is not clear and has therefore not been attempted. However, based on the logs the main water bearing unit, assumed to be the Cross Valley Aquifer, is located between 20 to 100 feet below ground surface. As described in Section 4.6, this unit represents the Advance Outwash (Qva) shown in plan on Plate 1. This unit is described within the logs as a "water bearing sand and gravel", "gravel with sand and water", "blue water bearing sand and gravel", "brown sand", "gray sand" and "gravel". During the February 4, 1999, site visit, an exposure of the advance outwash was located along the east side of Highway 9 at the intersection with Highway 522, approximately 1.5 miles south of the pipeline alignment. As illustrated in Appendix E, Photo # 12, the aquifer material at this location is a blue-gray silty sand with trace rounded gravel. At other locations, higher proportions of gravel are observed. Based on review of the local geology presented on Plate 1, the Cross Valley Aquifer daylights along the pipeline alignment at surface just north of 22Q01 in the Bear Creek area, in the topographic low west of 30C01 and in the topographic low in the vicinity of 19H01. During the field visit, evidence of the aquifer material at surface was noted along the pipeline alignment in the topographic low to the west of Echo Lake Road. This area is illustrated looking northwards from the Echo Falls Country Club in Appendix E, Photo #13 and at the base of the low in Appendix E, Photo #14. In this area, the surface soils are sandy with rounded gravel typical of the Advance Outwash deposits. These soils are illustrated in Appendix E, Photo #15.

As shown on Figure 4-2, the Cross Valley Aquifer is generally blanketed by a 20 to 100 feet thick layer described as a "clay hardpan", "sandy clay", "dark gray sandstone clay", "gray claystone", "sandy gravelly till", "gray cemented sand and gravel", "gravelly, sandy clay and silt". These descriptions refer to the Vashon Till, typically a very dense mix of clay, silt, sand and gravel. Appendix E, Photo #16 illustrates an outcrop of the till viewed on February 4, 1999, 1/4 mile south of the alignment, along the south side of the 10,000 block of 212th Street SE. To obtain a representative average content of the Vashon Till in this locality, geological descriptions on wells logs located within 1/2 mile north and south of the alignment were compiled as shown on Table 4-3. The % content of clay, silt, sand, gravel and boulders were estimated based on the descriptions and using the approximate proportions listed below:

Descriptive Term	Range of Proportion
trace	0-5%
little	5-12%
some or adjective*	12-30%
and	30-50%

* adjective: silty, sandy, gravelly etc.

For example, "a silt, some sand, trace gravel" describes a basic soil component of silt (30-50%), with minor components of sand (12-30%) and gravel (0-5%). As indicated on Table 4.3, the Vashon Till in along this area of the pipeline alignment comprises an average of 31% sand, 27% gravel, 26% clay, 11% silt and 1% boulders.

4.9 Hydraulic Properties

The hydraulic properties of the Vashon advance outwash have been estimated based on the results of pumping-tests conducted in the CVWD wells and also the two Woodinville Water District wells. Table 4-2 summarizes the results of these tests. Observations from these well testing data include the following:

- Most if not all of the wells are completed in a lower zone in the Vashon advance outwash. This zone occurs near the base of the formation above the transitional beds;
- The most productive zone contributing to the wells is about 30 feet to 40 feet in thickness, although the entire zone thickness may be slightly larger;
- The aquifer zone contributing to the wells is classified as semi-confined. The static water level is at higher elevation than the completion interval of the well, but vertical leakage occurs from higher portions of the aquifer;
- The aquifer transmissivity ranges from about 4,370 gallons per day per foot (gpd/ft) at Well 2 to 66,500 gpd/ft at Woodinville Well PW-1. This property of the aquifer indicates the ability for groundwater to flow through the soils. High values correspond to high groundwater flow rates and consequently highly productive water wells; and
- Hydraulic conductivity ranges from 18 ft/d to 255 ft/d, with an average value of 131 ft/d. These values pertain to the productive zones contributing to the wells rather than the entire formation. The hydraulic conductivity was estimated using the transmissivity and the effective aquifer thickness. The effective aquifer thickness was estimated from the well logs and represents the thickness of the productive zone contributing to the well.

The Woodinville Water District Wells, designated PW-1 and PW-2, also appear to withdraw groundwater from the Cross Valley Aquifer. Based on well testing in PW-1 and PW-2, it appears the aquifer is slightly more permeable in the location of these wells in comparison to the north where the CVWD wells are located. It is also noteworthy that aquifer transmissivity and hydraulic conductivity reported for these wells is different than that presented in the well construction reports (Hart Crowser 1994a, 1994b). Based on review of the well testing data, alternative interpretations were made, resulting in lower values for aquifer transmissivity. The lower values are consistent with typical values for the Vashon advance outwash.

The USGS study for the Snohomish County Groundwater Management Program (Thomas and others, 1996) presented hydraulic properties for the Vashon advance outwash and other hydrogeologic units. The USGS determined hydraulic conductivity based on the specific capacity from water wells in the area. As noted by the USGS (Thomas and others, 1996), the estimated hydraulic conductivity for the low permeability units (Q_{vt} , Q_{tb} , T_b) are biased

toward higher values, as wells were only completed in the most permeable materials encountered. The USGS estimated the following hydraulic conductivity values:

Hydrogeologic Unit	Hydraulic Conductivity (ft/d)		
	Minimum	Median	Maximum
Alluvium (Qal)	3.6	88	3,200
Vashon recessional outwash (Qvr)	0.08	180	1,800
Vashon till (Qvt)	0.04	50	1,000
Vashon advance outwash (Qva)*	3.4	42	310
Transitional beds (Qtb)	0.025	20	280
Undifferentiated deposits (Qu)	0.22	31	1,840
Tertiary bedrock (Tb)	0.0023		0.90

*Vashon advance outwash data reported for Intercity Plateau.

The hydraulic conductivity data presented above all pertain to the horizontal direction. The hydraulic conductivity, however, has a different value for groundwater flow in the vertical direction. In horizontally layered materials, the vertical hydraulic conductivity will be less than that for the horizontal direction. Vertical hydraulic conductivity may range from 1/10 to 1/1,000 of the horizontal value. In general, a higher horizontal hydraulic conductivity will correspond to a higher vertical hydraulic conductivity that, in some cases, structural or depositional anomalies (cracks, fissures, erosional features) can result in higher vertical hydraulic conductivity than would be predicted based on a percentage of the horizontal hydraulic conductivity. No measurements of vertical hydraulic conductivity were identified in the project area.

4.10 Groundwater Flow

The direction of groundwater flow can be determined using water level elevations measured in wells. Water levels are plotted on a map and contours are drawn to show lines of constant elevation. Groundwater flows from higher to lower elevations.

Groundwater flow within the Cross Valley Aquifer generally follows the local topography and moves from high altitude areas toward stream channels and the edges of the Plateau. Recharge travels vertically downward to the aquifer through the overlying layers. Mounds of groundwater typically occur under the areas of relatively higher topography with flow radially outward from the center of the mounds. On a regional basis, a groundwater divide exists along the center of the plateau area, trending in a northwesterly direction, similar to the path of the Snohomish River. Groundwater on the northeast side of the divide discharges toward the Snohomish River, while groundwater on the southwest side of the divide discharges toward Bear Creek or the Sammamish River. The position of this divide is not well defined, but it appears to run approximately through the center of the CVWD wellfields. Local flow patterns in recharge

areas do not necessarily correspond to regional flow directions. This is because there is a significant component of vertical flow in recharge areas, the distribution of recharge is not necessarily uniform, hydraulic gradients are generally flatter, and localized mounds can develop. Complex local flow patterns are likely on the Cross Valley recharge area. A combination of locally hummocky topography, the presence of perched lakes (for example, Echo Lake), and upland valleys (for example Paradise Valley) probably cause significant local variations in flow patterns.

Of particular note is the potential for a westward component of flow along the pipeline alignment in the vicinity of Echo Lake Road. In this area, Vashon Advance Outwash is exposed in a poorly drained topographic low. Detailed water-level measurements are not available from wells in this area, though several are known to exist. It is possible that there is flow from this area toward the CVWD wellfields, even under non-pumping conditions. This area may act as a head boundary, providing recharge to the aquifer, rather than acting as a discharge boundary, as is common at other surface exposures of advance outwash.

4.11 Groundwater Recharge

Groundwater recharge can occur from several sources including: 1) infiltration of precipitation; 2) leakage from surface water such as streams and lakes; 3) infiltration of irrigation water that is applied in excess quantities; and 4) infiltration of septic drainfield discharges. The primary mechanism for groundwater recharge in the Cross Valley Aquifer is the infiltration of precipitation. Additional recharge sources to the Cross Valley Aquifer exist but, in comparison, are minor.

The infiltration rate is typically estimated by conducting a water balance, which uses precipitation and runoff (streamflow) data to estimate infiltration. Infiltration rates are often estimated using the following equation:

$$I = P - R - ET(SM)$$

where:

I	is infiltration to groundwater;
P	is precipitation;
R	is surface water runoff; and,
ET(SM)	is evapotranspiration and is expressed as a function of soil moisture (SM).

Infiltration recharge has been estimated in several studies and ranges as follows:

- 4.8 inches (Ecology, 1998) : Based on CARA Guidance for the Bothell area;
- 8 inches (Golder, 1997): Based on Dunne and Leopold (1978)
- 15 to 19 in/yr. (Thomas and Others, 1996): Based on US Geological Survey analysis of for areas covered by till soils;

- 9.8 in/yr. to 20.6 in/yr. (Woodward et al. 1995): Based on estimates for several basins in southwestern King County which have land use and geologic similarities to the Cross Valley area.

The recharge estimate is important because of its control on the amount of water available for mixing with a potential contaminant and thus its potential concentration in groundwater. Groundwater is regulated by concentration (typically milligrams per liter), so accurate prediction of contaminant concentration is important. Lower recharge rates can result in higher contaminant concentrations per unit area because there is less water available for dilution. Therefore a predicted concentration of a contaminant reaching the water table based on simple mixing could vary over a factor of 5, depending on the actual recharge characteristics in the area.

4.12 Preliminary Wellhead Protection Area Delineation

4.12.1 Groundwater Model

Groundwater computer modeling was used to simulate groundwater flow within the Cross Valley Aquifer. The simulated groundwater flow system was subsequently used to determine preliminary wellhead protection areas for the CVWD wells. A Draft report to CVWD by Golder (1997) summarizes the results of the modeling. Figure 4-3 shows the predicted wellhead protection areas and a pathline analysis of steady state groundwater flowpaths from the proposed alignment toward CVWD wells.

The groundwater flow field simulated by the model generally matches both the hydraulic gradient and the direction of groundwater flow in the actual system. In this respect, the subsequent Wellhead Protection Area delineation is accurate within the limitations of the water-level data used to identify flow directions and gradients. The calibration, however, was difficult and in some categories the current model has deficiencies, including:

1. The model typically underpredicts the groundwater elevation at the calibration points.
2. A uniform effective hydraulic conductivity value of 15 ft/d was determined for Layer 1 (Vashon advance outwash). This is considerably lower than the measured transmissivity at CVWD pumping wells. In the vicinity of the pumping wells, the hydraulic conductivity is estimated to average 131 ft/d.
3. In delineating travel times, the effective porosity was adjusted to obtain groundwater velocities representative of the permeabilities observed in the Cross Valley Aquifer. The effective porosity was set to a value of 0.025, or 2.5%, to achieve groundwater velocities which equal those estimated to occur at the higher hydraulic conductivity.

The deficiencies are believed to be primarily the result of assigning a single uniform layer to represent the entire thickness of the Vashon Advance Aquifer.

In reality the layering and hydraulic conductivity likely varies spatially. At present, data are limited to define the layering and spatial distribution of hydraulic conductivity. A refinement of the model is being considered, but is probably not necessary to fulfill the objectives of the State Wellhead Protection Plan.

4.12.2 Contaminant Source Inventory

A contaminant source inventory (CSI) was developed through a search of state and federal databases for the contaminant sources occurring in the wellhead protection area buffer zone.

The following observations were made regarding the distribution of sources:

- No contaminant sources were identified within the buffer zone for Wells 7 and 7A;
- No contaminant sources were identified within the 10-year WHPA for the Woodlane Well and Wells 3 and 8;
- Nine sources were located within the 10-year WHPA for Wells 1, 5, 6, 9 and 10.
 - Two of these sources were located inside the 5-year WHPA and outside the 1-year WHPA.
 - Five of the sources were located within the 1-year WHPA;
- Most of the sources occur in two clusters. One is located at Clearview junction (SR 9 and 180th SE). The other is located south of Maltby Road near SR 522.

One of the requirements of wellhead protection is to notify owners/operators of potential contaminant sources that they are located within a wellhead protection area. This requirement was fulfilled for the initial source inventory.

The CVWD source inventory was reviewed to assign the potential sources to critical material user groups. A summary of the business class assignments follows:

<u>BUSINESS CLASS</u>	<u>NUMBER OF</u>
<u>SITES</u>	
Unassigned	10
Auto Repair, Parts, Machine Shops, Service	3
Building Maintenance, Cleaning Supplies, Manufact/Dist.	1
Building Materials Production and Sales	8
Garden Centers, Greenhouse Equipment and Supplies	1
Gasoline, Retail	3
Hardware Stores, retail sales	2
Metal Fabrication	1
Trucking Companies	6
Wood Products/Preservation	3

TOTAL

38

4.12.3 Wellhead Protection Area Delineation for Private Wells

A delineation of wellhead protection areas for known private wells was conducted using a calculated fixed radius method recommended by Washington Department of Health. The equation used is:

$$R = \sqrt{\frac{Q * t}{Pi * n * H}}$$

Where

Q = 5,000 gallons per day (Pumping Rate)

N = 0.22 (Porosity)

H = 5 feet (open interval)

Protection zones of 143 feet, 321 feet, and 455 feet were calculated for 1-year, 5-year and 10-year travel times respectively.

Figure 4-4 shows the wellhead protection areas for wells in the vicinity of the pipeline alignment that are on file with the Department of Ecology.

5. CONTAMINANT TRANSPORT AND PIPELINE SPILL IMPACTS

Releases of product from the Olympic Pipeline have the potential to impact the Cross Valley aquifer via 3 routes: 1) movement of product through the unsaturated zone directly to the water table; 2) via infiltration of rainfall through product-bearing soils above the water table; and, 3) contaminated surface water recharge to the aquifer. The two product types likely to be transported through the pipeline are gasoline and diesel. The following sections present a brief overview of mass transport of these materials within the subsurface and identify the key contaminants of concern. The overview is not exhaustive but aims to describe the main issues associated with release of gasoline and diesel from the pipeline and the potential for degradation of the Cross Valley Aquifer drinking water resources.

This section addresses the following topics, which were not discussed in the DEIS or application:

- Contaminant transport mechanisms
- Characterization and contaminants of concern in gasoline and diesel
- Documented pipeline releases in Washington
- Remedial alternatives for contaminated groundwater.

This section illustrates the complexity and site-specificity of contaminant transport in groundwater; the concern over a relatively contaminant in gasoline (MTBE), the length of time spent investigating and cleaning up pipeline spills in Washington; and the alternatives and limitations of potential treatment technologies, should a spill occur.

5.1 Product Migration

Gasoline and diesel are organic compounds that are immiscible with water and are known as nonaqueous phase liquids (NAPLs). Since both have densities less than that of water they are referred to as *light* nonaqueous phase liquids, or LNAPLs. When spilled at the land surface, LNAPLs migrate vertically through the unsaturated (vadose) zone and may reach the water table from where mass is dissolved and transported within the saturated zone by groundwater transport processes. In addition, residual LNAPL in the unsaturated zone will serve as a contaminant source of chemicals to groundwater via rainfall infiltration. Migration of LNAPLs within the unsaturated and saturated zones have different physical and chemical controls. These are described briefly below and illustrated in Figure 5-1.

5.1.1 Unsaturated Transport

If spilled at surface, a portion of the LNAPL spill will volatilize into the atmosphere and a portion will migrate vertically downwards through the vadose zone under the influence of gravity and capillary forces towards the water table. An LNAPL migrates downwards by moving from pore to pore displacing soil gas

and pore water that are not tightly held to grains by surface tension. Downward movement of the LNAPL occurs only if there is sufficient LNAPL volume to overcome surface tensions. As downward migration occurs, the quantity of mobile contaminant gradually decreases because some of the LNAPL is trapped in each pore and remains at residual saturation. Therefore the quantity of free product reaching the water table is less than the spill volume. If the spill is relatively small, downward percolation in the unsaturated zone will stop when the total volume is at residual saturation. As the LNAPL moves downwards through the vadose zone, the LNAPL plume may spread horizontally due to capillary forces and the presence of layers of varying hydraulic conductivity. LNAPL at residual saturation can therefore represent a long-term, continuing source of contaminants which will be transported to the water table by dissolution into rainwater infiltration and movement downwards to the water table.

LNAPL within the vadose zone can partition into the vapor phase as well as the soluble phase in capillary water. The degree of the partitioning will depend upon the relative volatility of the material and its solubility in water.

If a sufficient quantity is spilled to saturate the vadose zone, the LNAPL will reach the top of the capillary zone and will accumulate. At the capillary zone, water is held in place above the water table by capillary forces (similar to water in a straw which is placed in a glass of water). As additional LNAPL accumulates above the capillary zone, positive pressure will increase until the LNAPL moves through the capillary fringe to rest directly on the water table.

5.1.2 Saturated Transport

At the LNAPL - water table contact, soluble components of the product will be dissolved into the groundwater and will move from the source area along the direction of groundwater flow.

Considering an LNAPL source at the water table, there are four basic processes that determine the extent of contaminant migration: advection, dispersion, diffusion and chemical reaction.

Advection is the transport of a chemical species in solution by groundwater flow and occurs at the average groundwater velocity. Advection is a function of the hydraulic conductivity and porosity of the geologic media as well the groundwater flow gradient.

Dispersion results from local variations in groundwater velocity caused by zones of differing hydraulic conductivity. The net result of dispersion is to spread the dissolved species through a larger volume of the saturated media than would be predicted by advection alone. Dispersion is a characteristic of the media through which the contaminant migrates.

Diffusion is a molecular scale process by which solutes (dissolved species) move from regions of higher concentration to regions of lower concentration in

response to a concentration gradient. Dispersion and diffusion have similar effects. i.e. the chemical is spread into a larger volume of water. Dispersion is generally the dominant process. However, diffusion is the dominant transport process in low permeability media.

Chemical reactions include a number of geochemical and biochemical processes which affect the movement of the contaminant. Important processes include volatilization, dissolution, sorption and degradation. The net effect of these processes is to slow down the rate at which the dissolved species migrates through the subsurface or to remove chemical mass. Chemical reactions are controlled by specific chemical properties of each dissolved species and of the aquifer materials.

5.1.3 Predicting Contaminant Transport

The process of contaminant migration in the subsurface is complex and is controlled by site-specific and chemical-specific properties. To predict contaminant mass transport and ultimately the concentrations of critical contaminants at receptors (i.e. a well), a detailed understanding of the local hydrogeology is required and also the physical / chemical reactions that are likely to control migration of the contaminants. Due to the number of variables and different mathematical equations that are required to predict contaminant mass transfer, a number of different computer programs of varying complexity exist as tools to predict the changes in contaminant concentrations from the source to the receptor. For a contaminant mass transport model to be sufficiently accurate, each hydrogeologic and physiochemical input value must be relevant to the study site.

The remainder of this section summarizes the important physical and chemical characteristics of gasoline and diesel which control migration of these products within the subsurface.

5.2 Product Characterization

This section describes the make up of gasoline and diesel, identifies the critical contaminants within each product in terms of groundwater contamination, and discusses applicable groundwater quality criteria.

5.2.1 Gasoline

Gasoline is a mixture of over 200 hydrocarbons (petroleum-derived chemicals) and a few synthetic products (added to improve fuel performance) (State of California, 1989). Hydrocarbons are any molecule that contains only hydrogen and carbon, both of which are fuel molecules that can be utilized as fuel. An example chemical composition of gasoline is presented in Appendix D. Broken down into major hydrocarbon groups, modern gasolines comprise approximately 55-60 % (by weight) saturated hydrocarbons (alkanes, such as pentane), 25-30 % (by weight) alkyl benzenes (aromatics, including benzene,

ethylbenzene, toluene, and xylene), 5 % (by weight) alkenes (for example pentene) and minor polynuclear aromatic hydrocarbons (such as naphthalene). The remaining 5-15 % (by weight) of gasoline is made up of oxygenates which contain oxygen in their structure as well as hydrogen and carbon. Examples of oxygenates include alcohols (such as methanol and ethanol), methyl tertiary butyl ether (MTBE), tertiary amyl methyl ether (TAME) and ethyl tertiary butyl ether (ETBE). Some gasolines also contain minor amounts of additives such as alkyl leads (tetramethyl lead and tetraethyl lead) and lead scavengers such as ethylene dibromide and ethylene trichloride. Leaded and unleaded gasoline contain a maximum of 1.1 and 0.013 gram of lead per liter respectively (State of California, 1989).

In terms of groundwater contamination, the gasoline components of most concern include the major aromatics (benzene, ethylbenzene, toluene and xylenes, referred to collectively as BTEX) and MTBE. Table 6.1 presents a summary of the physical and chemical properties of these components. The main reasons for concern are: 1) these compounds are known to pose or may pose a serious threat to human health; 2) they have the potential to move rapidly through soil and groundwater; and 3) BTEX vapors are highly flammable and explosive.

5.2.2 Diesel

Diesel is a type of fuel oil most commonly used as a transportation fuel for diesel engines. It consists primarily of straight chain hydrocarbons ranging in length from C10 to C23 in addition to minor amounts of aromatic hydrocarbons (including benzene) and polynuclear aromatic hydrocarbons (PAHs). An example chemical composition for diesel fuel is presented in Appendix D. ATSDR (1997) reports that the partitioning of diesel into drinking water after 17 hours of incubation resulted in only 1% being dissolved in the water. The water soluble fractions contained primarily aromatic constituents (>93%) and naphthalenes (types of PAHs). Therefore, in terms of groundwater contamination, the diesel constituents of most concern are aromatics (BTEX) and naphthalenes. In addition, some PAHs may be a concern due to their known carcinogenic effects (for example, benzo(a)pyrene). These PAHs are commonly referred to as carcinogenic polycyclic aromatic hydrocarbons (CPAHs). Table 6.1 presents important physical and chemical properties for the contaminants of concern within diesel.

5.2.3 Drinking Water Standards

National Primary Drinking Water Regulations (NPDWRs) are legally enforceable standards that apply to public water systems across the United States. NPDWRs are set by the EPA to protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health. For BTEX and benzo(a)pyrene, the criteria levels listed on Table 6.1 are Maximum Contaminant Levels (MCLs), the maximum level of a contaminant allowed in drinking water under the federal drinking water standards. In addition, drinking water criteria for Washington State are published in WAC 170-200-

030. For benzene, the Washington State criterion is more stringent (1.0 ug/L) than the EPA MCL (5.0 ug/L).

Enforceable criteria for MTBE, naphthalene and methynaphthalene have not been set either federally or by Washington State. For MTBE, the limit range shown on Table 6.1 is an EPA official health advisory level based on both health and aesthetic concerns. For naphthalene, analysis of a drinking water source in Washington State must include naphthalene (as an indicator of diesel contamination) to a 0.5 ug/L detection limit.

In terms of gross gasoline and / or diesel contamination, Washington State remediation standards require that groundwater contains no more than 1 mg/L of total petroleum hydrocarbons (TPH).

5.3 Contaminant Fate

This section focuses on the physical properties and chemical reactions that control the movement of and changes in contaminant mass from a hypothetical spill area (the source) to a potential downgradient drinking water supply well (the receptor). The processes include volatilization, dissolution, sorption and degradation. Table 6.1 summarizes the important physical and chemical properties for critical gasoline and diesel constituents which influence these processes.

5.3.1 Volatilization

Volatilization is the evaporation of organic compounds dissolved in the aqueous phase. Volatilization results in mass transfer from the liquid phase to the vapor phase and is controlled by the vapor pressure of the compound. The vapor pressure describes the compound's tendency to evaporate and is essentially the solubility of an organic solvent in a gas. The transfer of the pure phase to the vapor phase is described by Raoult's Law and is a function of the mole fraction of the particular compound (for example, benzene) within the mixture and the vapor pressure of the pure compound. The higher the vapor pressure, the greater the tendency for the solvent to volatilize. The transfer of dissolved constituent to the vapor phase is described by Henry's Law and is a function of the concentration of the pure compound in solution and the Henry's Law Constant. The greater the Henry's Law Constant, the greater the tendency for the organic compound to partition into the gas phase. Volatilization is important in the unsaturated zone since it provides a mechanism for dissolved contaminant mass to be reduced prior to entering the groundwater. Volatilization may also represent an exposure pathway especially if confined spaces are present where vapors may accumulate.

5.3.2 Dissolution

Dissolution controls the concentration of the contaminant entering the dissolved phase from the source (for example, gasoline pooled on the water

table or rainwater moving through a zone of residual saturation). Water solubility (S_o) indicates the amount of the compound that will dissolve in distilled water. The higher the water solubility of a compound, the greater the potential for the compound to be mobile in the environment. The most soluble organic compounds are those that can form hydrogen bonds with water (polar molecules) or compounds containing oxygen or nitrogen. For non-polar molecules (such as BTEX), the smaller the molecule, the greater the water solubility. Hydrophobicity is a measure of the degree to which an organic substance will preferentially dissolve in water versus an organic solvent. If an organic substance is hydrophobic, it will preferentially dissolve in an organic substrate. Hydrophobicity is measured by the octanol-water partition coefficient (K_{ow}). Usually given as a logarithm, the greater the value, the greater the tendency for the compound to dissolve in the solvent rather than the water. In general, the higher the K_{ow} , the lower the water solubility and the more likely the molecule is to sorb.

5.3.3 Sorption

Sorption describes the process by which a dissolved molecule adheres to a solid surface such as a soil particle. The net result is the removal of solute from solution. Sorption is determined by measuring how much of a solute can be sorbed by a particular material and is a function of the concentration of the solute and the distribution coefficient (K_d) of the molecule. The K_d can be estimated as the product of the weight fraction of organic carbon (f_{oc}) in soil and the organic carbon to water partition coefficient (K_{oc}). The K_{oc} indicates the degree to which an organic compound will preferentially adsorb to organic carbon within the soil matrix rather than remain dissolved within water. Under the same aquifer conditions, the greater the organic carbon to water partition coefficient of the species, the less mobile the species tends to be in the subsurface. Compounds with a $K_{oc} < 100$ are considered to be moderately to highly mobile (ATSDR, 1997).

5.3.4 Degradation

Degradation is defined as the process whereby an organic molecule becomes smaller by chemical means (abiotic degradation) or biological means (biodegradation). Hydrolysis is an example of abiotic degradation and involves a reaction between an organic molecule and water to form an alcohol. Hydrolysis is generally only significant for organic molecules containing an attached halogen, carbon, nitrogen or phosphorous atom for which substitution by an OH^- is energetically favorable. Since the major components of gasoline and diesel do not possess these sites, hydrolysis is not a significant degradation process. For the critical constituents of gasoline and diesel, biodegradation is the most important degradation mechanism in the subsurface. This mechanism requires microorganisms to convert the contaminants by using the contaminant molecules as a food source or as an electron acceptor. To sustain the microbes, a suitable substrate (carbon energy source, i.e. the petroleum hydrocarbon), electron acceptor (for example oxygen) and nutrients are required. Microbial degradation in the subsurface is influenced by many

factors such as contaminant concentration, microbial population, soil permeability, dissolved oxygen content, redox potential, nutrients, salinity, other sources of carbon, inhibitors, temperature and pH. As a class, petroleum hydrocarbons are generally biodegradable in aerobic conditions. The lighter, soluble members are generally biodegraded more rapidly and to lower residual levels than are the heavier, less soluble members. Therefore, monoaromatic compounds such as BTEX are more rapidly biodegraded than the two-ring compounds such as naphthalene.

5.4 Contaminants of Concern

The following sections present some background and a brief summary of how the contaminants of concern within gasoline and diesel are likely to behave in the subsurface and their toxicity in terms of human health. Table 6.1 provides a summary of the important physical and chemical properties of these compounds which influence their fate in the environment.

5.4.1 Benzene

Background

Benzene is a colorless liquid with a sweet odor (ATSDR, 1997). It enters the environment primarily from production, storage, transport, venting and combustion of gasoline. It occurs at between 0.12 to 3.5 % (by weight) in gasolines and at very low concentrations in diesel (State of California, 1989). Benzene is a known human carcinogen. WAC 173-200-030 stipulates a maximum concentration level of 1 ppb (ug/L) in drinking water.

Environmental Fate

Since benzene is highly volatile, a large proportion will escape to the atmosphere by partitioning into the vapor phase at surface and within the unsaturated zone. Since benzene is only moderately soluble, its solubility controls the rate at which it dissolves in groundwater. However, once dissolved, with a K_{oc} of between 32 - 143, benzene is considered highly mobile, with a tendency to remain dissolved within water rather than adsorb on to aquifer material. A model developed to predict the fate of benzene following leakage of gasoline from an underground storage tank at Vero Beach in Florida indicated that 67% of benzene in the gasoline would volatilize within 17 months. Of the remaining benzene, 29% would leach to groundwater, 3% would remain in the unsaturated zone and 1% would be degraded (ATSDR, 1997).

Biodegradation, principally aerobic, is the most important mass reduction process of benzene in the environment. Benzene is biodegraded in soil under aerobic conditions (ATSDR, 1997) with a half-life on the order of 28 days. However, laboratory studies indicate that oxygen and nitrate concentrations are major controlling factors. Chiang et al. (1989) found that a minimum dissolved oxygen concentration of 0.9 mg/L in groundwater was necessary for complete aerobic degradation of benzene. Additional studies suggest that anaerobic

biodegradation is unlikely (Howard, 1990). Benzene is resistant to abiotic degradation due to its stable structure and lack of substitution sites.

Exposure

Virtually all (99.9%) benzene released to the environment finally distributes itself into the air and inhalation is the dominant pathway of human exposure (ATSDR, 1997). However, releases of benzene from USTs and pipelines have the potential to impair drinking water resources and individuals may be exposed to high concentrations of benzene in their drinking water if they obtain tap water from wells located near these sources.

Toxicity

Acute benzene exposure causes depression of the central nervous system. Human exposure (5-10 minutes) to very high levels of benzene in air (10,000 - 20,000 ppm) can result in death. Brief exposure to concentrations of 700 - 3,000 ppm in air irritate the eyes and respiratory system and can cause drowsiness, dizziness, rapid heart rate, headaches, tremors, confusion and unconsciousness. Eating foods or drinking water containing high levels of benzene can cause vomiting, irritation of the stomach, dizziness, sleepiness, convulsions, rapid heart rate, coma and death. The health effects of ingesting benzene at lower concentrations are unknown (ATSDR, 1997).

Exposure to low levels of benzene over a long period of time can disrupt normal blood production and result in anemia, excessive bleeding and is associated with increased incidences of leukemia. After exposure to benzene stops, blood production may return to normal. The most significant toxic effect of chronic benzene exposure is aplastic anemia, an often irreversible injury to the bone marrow.

5.4.2 Ethylbenzene

Background

Ethylbenzene is a colorless liquid that smells like gasoline (ATSDR, 1997). It occurs naturally in coal tar and petroleum and is found in many man-made products including inks, paints and insecticides. Ethylbenzene is released to the environment primarily from emissions, wastewater, leaks and spills associated with its production and via emissions from petroleum refining, vaporization losses and spills of gasoline and diesel fuel (Howard, 1990). It occurs at between 0.36 to 2.86 % (by weight) in gasolines and at very low concentrations in diesel. EPA National Primary Drinking Water Standards (NPDWSs) stipulate a maximum concentration level of 700 ppb (ug/L) in drinking water.

Environmental Fate

Due to its relatively high vapor pressure, ethylbenzene releases to surface soil will result in substantial losses to the atmosphere (although ten times less than benzene) as well as infiltration into the subsurface. Vapor phase transport will occur within the unsaturated zone (due to a relatively high Henry's Law Constant) by partitioning from the dissolved phase into air pockets within unsaturated soil pore spaces. Sorption and retardation by soil organic carbon will occur to a small extent but will not be significant enough to prevent migration in most soil types typically encountered in the environment. Since ethylbenzene is approximately 10 times less soluble than benzene, concentrations within groundwater from the same source are likely to be significantly lower.

Although no information was found on the rate at which biodegradation occurs, there is evidence that aerobic microbes are able to biodegrade ethylbenzene slowly in soil and groundwater. At high concentrations, there is evidence that resident microbes can be killed (Howard, 1990). Anaerobic biodegradation may occur, although at significantly slower rates than aerobic biodegradation (ATSDR, 1997). Ethylbenzene will not hydrolyze in soil or groundwater (Howard, 1990).

Exposure

The highest exposures to the general public are likely to occur through the use of self-service gasoline pumps. Residential wells downgradient of leaking underground storage tanks, pipelines or landfills may contain elevated levels of ethylbenzene.

Toxicity

Ethylbenzene is a skin and mucous membrane irritant. At high concentrations it causes narcosis. Liver and kidney damage, nervous system changes and blood changes have been associated with laboratory animals exposed to high concentrations. Humans exposed briefly to 1,000 ppm experienced eye irritation; 2,000 ppm caused lacrimation and nasal irritation; 5,000 ppm produced intolerable irritation of the eyes and nose. When chronic exposures exceeded 100 ppm, symptoms included fatigue, headache and mild irritation of the eyes and respiratory tract (ATSDR, 1997).

Ethylbenzene does not cause damage to the hematopoietic system despite its chemical similarity to benzene. There is no clear evidence that reproductive effects occur after exposure to ethylbenzene. Ethylbenzene is not classified as a carcinogen (ATSDR, 1997).

5.4.3 Toluene

Background

Toluene is a clear, colorless liquid with a distinctive smell (ATSDR, 1997). It occurs naturally in crude oil and in the tolu tree. It is produced in the process of making gasoline and other fuels from crude oil, in making coke from coal and as a by-product in the manufacture of styrene. Toluene is used in making paints, paint thinners, lacquers, adhesives and rubber (ATSDR, 1997). It occurs at between 2.73 to 21.8 % (by weight) in gasolines and at very low concentrations in diesel (State of California, 1989). EPA National Primary Drinking Water Standards (NPDWSs) stipulate a maximum concentration level of 1,000 ppb (ug/L) in drinking water.

Environmental Fate

Considerable amounts of toluene are spilled on land during the storage, transport and disposal of fuels and oils (Howard, 1990). Since it is sufficiently volatile (28.4 mmHg at 25 degrees C), the majority of toluene released at surface partitions to the air. Under typical conditions, more than 90% of toluene in the upper soil layer volatilizes to air within 24 hours (ATSDR, 1997).

The K_{oc} for toluene ranges between 37 to 178 which indicates that toluene will be leached rapidly from soils with a low organic carbon content. Since toluene is approximately one third as soluble than benzene, concentrations within groundwater from the same source are likely to be significantly lower.

Studies indicate that toluene can be degraded by a number of microorganisms in both aerobic and anaerobic conditions. Based on data from the aerobic degradation of toluene in water, the biodegradation half-life of toluene in soils is expected to range from 4 to 22 days.

Exposure

Based on average values of toluene in water, exposure by ingestion of contaminated drinking water is likely to be relatively small compared to inhalation. As for other BTEX components, the greatest exposure to the general public is likely to be from inhalation at self-service gasoline pumps. People who work with gasoline, diesel, kerosene, heating oils, paints and lacquers are at the greatest risk of exposure.

Toxicity

The primary health concern related to toluene is its narcotic and toxic effects on the central nervous system. Short-term exposure to low-to-moderate concentrations in air can produce fatigue, weakness, confusion, memory loss and nausea. Long term exposures to high concentrations due to intentional abuse have been associated with permanent central nervous system damage.

Toluene may change the way kidneys function and if alcohol is consumed along with a toluene exposure, the combination may affect the liver more than either compound alone. Combinations of toluene and some common medicines like aspirin and acetaminophen may increase the effects of toluene on hearing (ATSDR, 1997). Toluene is not classified as a carcinogen (ATSDR, 1997).

5.4.4 Xylene

Background

Xylene is a colorless liquid with a sweet smell (ATSDR, 1997). In this text, the terms xylene, xylenes and total xylene will be used interchangeably. There are three forms of xylene in which the positioning of the methyl (CH₃) groups on the benzene ring differ. Xylene is principally a synthetic chemical produced from petroleum. Xylene also occurs naturally in petroleum and coal tar and is formed during forest fires. It is one of the top 30 chemicals produced in the US and is used as a solvent in the printing, rubber and leather industries (ATSDR, 1997). Total xylene occurs at between 3.22 to 8.31 % (by weight) in gasolines and at very low concentrations in diesel (State of California, 1989). EPA National Primary Drinking Water Standards (NPDWSs) stipulate a maximum total xylene concentration level of 10,000 ppb (ug/L) in drinking water.

Environmental Fate

Volatilization is the dominant transport mechanism for xylene. Globally, 99.86% of xylenes released to the environment ultimately partition into the atmosphere (ATSDR, 1997). When spilled on to the ground, xylene will volatilize or be leached into the ground. The K_{oc} for xylene ranges between 25 to 204 which indicates that toluene will be leached rapidly from soils with a low organic carbon content but will tend to sorb on to soil organic matter. Since xylene is approximately one third as soluble than benzene, concentrations within groundwater from the same source are likely to be significantly lower.

Xylene generally appears to be poorly to moderately biodegraded in groundwater and has been observed to persist in groundwater particularly at sites where concentrations are high (likely due to toxic effects on resident microbes). Research indicates that xylene can be aerobically biodegraded. Under denitrifying conditions, biodegradation of m- and p- xylene have been reported to occur within 40 days (ATSDR, 1977) and, although o-xylene was resistant to degradation when it was the sole carbon source, it was slowly removed in the presence of other hydrocarbons. Under anaerobic sulfate-reducing conditions biodegradation of xylene is also facilitated (ATSDR, 1977). Little or not abiotic degradation is anticipated (ATSDR, 1997).

Exposure

As for toluene, exposure by ingestion of contaminated drinking water is likely to be relatively small compared to inhalation. The greatest exposure to the general

public is likely to be via inhalation of indoor and workplace air, automobile exhaust, smoking and inhalation of solvents containing xylene.

Toxicity

Xylene vapor is an irritant to the skin, eyes, nose and throat. At high concentrations, it causes narcosis and may result in liver and kidney damage. Information from animal studies suggests no evidence of carcinogenicity. Dose dependent retardation of fetal development has been reported in animal studies, but has not been documented in humans (ATSDR, 1997).

5.4.5 MTBE

Background

Methyl tertiary butyl ether (MTBE) is the most frequently used oxygenate in the US (EPA, 1998). More than 10 billion kg MTBE was used in US gasoline in 1996 (EPA, 1998). Gasolines now contain between 1 to 8 % MTBE (by weight) and may contain up to a maximum of 15 % MTBE (by weight) (EPA, 1998). The primary uses of MTBE in gasoline are to reduce carbon monoxide levels, particularly at cold times of the year, to reduce emissions of ozone precursors and also certain toxic organic air pollutants.

The 1998 EPA Contaminant Candidate List (CCL) identified MTBE as a contaminant with specific data gaps in the areas of health effects and occurrence data. These data gaps must be filled in order for EPA to make a scientifically informed determination as to whether or not MTBE should be regulated with a health-based National Primary Drinking Water Regulation. Currently, the US EPA health advisory level for MTBE in drinking water is 20 to 40 (ug/L).

Environmental Fate

The transport of MTBE and other oxygenates through aquifers would be expected to occur at nearly the same velocity as the ground water. MTBE is more soluble in water and less sorbed to soils than the other major organic compounds in gasoline, namely, benzene, toluene, ethylbenzene, and xylenes (BTEX). Consequently, MTBE and other oxygenates would be expected to be at the leading edge of the plume or, in the extreme case over a long period of time, could become completely separated from the rest of the plume if the original source of oxygenate were eliminated.

The impact that biodegradation will have on MTBE plume movement is currently not well understood (EPA, 1988). Results from field studies of the natural biodegradation of MTBE in ground water show that the processes involved generally take place at very slow rates or with long lag times, and depend on site-specific geochemical conditions. Schirmer and Barker (1998) found that during the first 16 months following a controlled injection of oxygenated gasoline in a sandy aquifer in Ontario, there was little evidence for

the biodegradation of MTBE. However, when the aquifer was sampled seven years later, the mass of MTBE had declined by more than an order of magnitude. Although the authors hypothesized that natural biodegradation may have been responsible for this disappearance, they noted the need for confirmatory lines of evidence to support this hypothesis. In contrast, Landmeyer et al. (1998) studied an accidental spill in South Carolina over a five year period and concluded that dispersion and dilution were primarily responsible for decreases in the concentration of MTBE, with biodegradation playing a very minor role.

Additional research needs include experimental measurement of biodegradation rates, identification of by-products and characterization of their environmental fate. This information is needed to develop a complete picture of the effects of oxygenates on the environment and consequently the risks they may pose.

Occurrence

Releases of fuel oxygenates occur during manufacture, distribution, storage, and use, particularly from point sources such as underground storage tanks (USTs), pipelines, and refueling facilities. Impacts to water resources can be loosely grouped into two categories: (1) widespread impacts occurring at low concentrations and (2) local impacts occurring at high concentrations. The first group is often the result of indirect sources, such as vehicular emissions of oxygenates that dissolve in rainfall and subsequently infiltrate to ground water, and may be spread over large areas. Also, leakage from motorized recreational water craft can be considered a diffuse source of contamination of surface water bodies such as reservoirs. The second category results from direct releases to surface and ground water from such sources as leaking USTs, pipelines, or tank cars.

Monitoring of groundwater quality by the US Geological Survey (USGS) indicates that MTBE has become detectable in shallow groundwater samples in certain urban areas in recent years, with concentrations ranging from below the reporting level of 0.2 µg/L to over 20,000 µg/L (EPA, 1998a). Recently, drinking water wells in Santa Monica, CA, were shut down because of MTBE contamination from one or more leaking USTs (Geraghty & Miller, Incorporated, 1996). Despite recent and ongoing studies, it is not clear whether the greater impact from MTBE or other fuel oxygenates to ground water is from diffuse (precipitation) or point sources (spills or leaks from fuel containers). Although relatively high groundwater concentrations may be readily associated with point source releases, concentrations on the order of 10 µg/L or lower could be associated with nonpoint sources as well as point sources (National Science and Technology Council, 1997).

Although scattered incidents of localized water contamination by MTBE have been reported since the early 1980s, the first report to suggest that oxygenate contamination of water might be occurring on a widespread basis came as a result of the USGS National Water Quality Assessment (NAWQA) program. Designed to assess the status and trends in the quality of ground and surface

water resources of the nation, the NAWQA program began sampling ground waters for MTBE in 1993 (and added TAME, ETBE, and DIPE in 1996). In an initial analysis of the NAWQA program's first 20 study areas or units, MTBE was the second most frequently detected volatile organic compound (VOC) in shallow ground water from selected urban areas monitored during 1993 and 1994 (Squillace et al., 1996).

The possibility exists that some UST system components, such as fiberglass reinforced plastic (FRP) tanks and piping and flexible piping, may be permeable to MTBE and other oxygenates. Such permeability might account for cases of MTBE contamination at gasoline stations where no leak could be detected and no other gasoline constituents were found. In addition, elastomer seals, used for gaskets and o-rings throughout UST systems and petroleum pipelines, may have compatibility problems with oxygenated fuels. An American Petroleum Institute (1994) survey indicated that petroleum pipeline and terminal managers had noticed significant deterioration of many different types of elastomers associated with fuel oxygenates.

Exposure

Based on limited monitoring and occurrence data, a potential for exposure of biota and human populations to oxygenates exists. Exposure implies actual contact with a contaminant, not just the existence or occurrence of the substance in the environment. Exposure characterization requires information on the magnitude and distribution of exposures. Among many factors that can affect exposure to oxygenate-contaminated water, unpleasant odor and taste have been reported as particularly notable in the case of MTBE in drinking water (EPA, 1998). However, it cannot be assumed that the sensory properties of oxygenates would prevent human population exposures to such contaminants. Individuals vary greatly in sensory and subjective reactions, and indeed, anecdotal evidence indicates that some individuals may have unknowingly consumed drinking water contaminated with MTBE at levels exceeding 35 µg/L (Maine Department of Human Services, Bureau of Health, 1998). Also, young children could be exposed via infant formula and beverages prepared with oxygenate-contaminated water. Taste and odor detection thresholds for MTBE have been reported ranging from 24 to 135 µg/L for taste and from 15 to 180 µg/L for odor (EPA, 1998). The detection threshold is typically defined as the concentration at which a subject can detect a taste or odor difference between a standard (e.g., "plain" water) and the diluted test substance on a specified percentage (e.g., 50%) of the trials.

Besides direct ingestion, human exposure to MTBE contaminated drinking water may occur due to food preparation, dish washing, laundering, and bathing. In particular, showering affords a significant exposure potential by the inhalation and dermal routes (EPA, 1998).

To date, limited empirical information is available either on the overall distribution of exposures to oxygenates in water for the US population as a

whole or on “high-end” exposure scenarios where oxygenate contamination is already known to occur.

Toxicity

Most of the testing and research on the toxicity of oxygenates has been concerned with the effects of inhaled MTBE in laboratory animals and human volunteers. Little information exists on the effects of ingested MTBE on humans. A few studies have examined the toxicity of MTBE in laboratory animals via the oral route of exposure (EPA, 1998). None of these studies used drinking water as a medium for administering MTBE to animals; rather, they typically delivered MTBE mixed in olive oil or corn oil in a bolus dose through a tube into the stomach. This method does not correspond very well to the way that drinking water is typically consumed by people.

5.4.6 Naphthalene and 2-Methylnaphthalene

Background

Naphthalene is a white solid that evaporates easily and has a strong smell (mothballs). 2-Methylnaphthalene is also a solid. Both are PAHs and are soluble in alcohol and benzene (ATSDR, 1997). Both compounds occur naturally as a component of crude oil. Due to minimal drinking water contamination associated with these compounds in the US, drinking water quality criteria have not been set for these compounds. However, analysis of a new drinking water source in Washington State requires analysis of naphthalene at a 0.5 ug/L detection limit. As indicated in Appendix E, naphthalene and methylnaphthalene occur within diesel at 0.13 % (by weight) and in the range of 0.57 - 0.91 % (by weight) respectively (State of California, 1989).

Environmental Fate

Naphthalene and 2-methylnaphthalene are relatively easily volatilized from soils and have relatively low solubilities in water which result in a limited mass being partitioned to groundwater. Once within groundwater, these compounds have a high tendency to sorb on to aquifer material. As a result, these PAHs are generally only detected in groundwater as a result of a very large spill or a spill that occurs over a long timeframe.

Both naphthalene and 2-methylnaphthalene are biodegraded in aerobic conditions. Complete aerobic biodegradation of naphthalene was observed in 8 days in gas-oil contaminated groundwater (Howard, 1990). Biodegradation of 2-methylnaphthalene was noted in aerobic sediments with a half life of 14 to 50 weeks (ATSDR, 1997). Anaerobic biodegradation and abiotic degradation of these compounds is not expected to be significant.

Toxicity

Human ingestion of large amounts of naphthalene (such as mothballs) may cause damage or destroy some red blood cells. However, insignificant health effects are anticipated as a result of ingesting naphthalene and/or methlynaphthalene contaminated groundwater. Neither naphthalene nor methlynaphthalene have been classified in terms of its carcinogenicity to humans (ATSDR, 1997).

5.4.7 Benzo(a)pyrene**Background**

Benzo(a)pyrene is a carcinogenic polycyclic aromatic hydrocarbon (CPAH). It is a pale yellow solid white solid that is soluble in benzene, toluene and xylene (ATSDR, 1997). It occurs naturally as a component of crude oil and at very low concentrations within diesel (0.07 ug/kg) (State of California, 1989). Due its known carcinogenic effect, EPA National Primary Drinking Water Standards (NPDWSS) stipulate a maximum benzo(a)pyrene concentration level of 0.2 ppb (ug/L) in drinking water.

Environmental Fate

Due to the very low vapor pressure and Henry's Law Constant, minimal volatilization occurs on land or in the subsurface. Migration of this component through the subsurface is likely to occur at a very slow rate due to its high tendency to sorb to soils and aquifer material. In addition, its very low water solubility results in limited partitioning into the aqueous phase. In summary, benzo(a)pyrene is not significantly mobile in the environment in comparison to other critical gasoline and diesel components. As a result, this CPAH is generally only detected in groundwater as a result of a very large spill or a spill that occurs over a long timeframe.

Aerobic biodegradation of benzo(a)pyrene is expected to occur based on reports of aerobic biodegradation of other PAHs. However, an estimated rate of reaction is not available (ATSDR, 1997). Abiotic degradation is not expected to be significant.

Toxicity

Benzo(a)pyrene is a known animal carcinogen and is probably carcinogenic to humans (ATSDR, 1997).

5.5 Pipeline Spills In Washington

A search was completed of WDOE files for confirmed and suspected surface water, soil and groundwater contamination related to pipelines. The following sites were identified in King, Skagit and Whatcom Counties as having confirmed releases of petroleum hydrocarbons to the subsurface as a result of pipeline

failures. No confirmed or suspected releases from petroleum hydrocarbon pipelines were identified in Snohomish County.

Olympic Pipe Line Company, Burlington - On August 14, 1983, 42,000 gallons of diesel spilled at the Allen Station site in Burlington and resulted in contamination of soil, groundwater, surface water and sediment. The cause of the leak was failure of a flange gasket. By 1986, 80% of the product had been recovered by a combination of mainly excavation and pump and treat. Groundwater monitoring is ongoing.

Olympic Pipe Line Company, Renton - On 6th October, 1986, a pipeline block valve (a pressure sensing device) leak was detected as a product seep into the Cedar River. The leak occurred 1.5 miles east of Renton in a residential area of Maplewood. Based on an estimated travel time from the block valve to the river of 11 months (Geoengineers, 1998), it was estimated that the valve had been leaking since the fall of 1985. Approximately 80,000 gallons of a gasoline/diesel mix migrated from the leak through the vadose zone to the water table and migrated as free product on the water table and as a dissolved plume beneath a number of residences in a westerly direction to the Cedar River. The plume was reportedly 1,200 feet long and a maximum of 350 feet wide at the downgradient margin of the plume. The City of Renton operates two well fields in the vicinity: the downtown well field located 1.5 miles west of the site and the golf course wells located 0.75 miles east of the site. Groundwater modeling indicated that the downtown wells are not at risk (Geoengineers, 1998) and, due to their completion in a deeper aquifer, the golf course wells are not thought to be at risk, although this has not been confirmed. The City's wellfield was not pumped throughout the accident, and the City are now developing an aquifer protection plan, funded by OPC, to manage pipeline risks to the aquifer. Assessment and clean up at the site involved air monitoring at nearby residences, installation of over 30 shallow monitoring wells and groundwater pump and treat system in conjunction with air sparging and soil vapor extraction. Remediation efforts are currently on going. At present, ten of the monitoring wells are not in compliance with MTCA A clean up standards (Geoengineers, 1998).

Olympic Pipe Line Company, Kent - On August 23, 1989, a gasoline spill was detected due to a pipeline block valve leak and resulted in BTEX and TPH contamination of groundwater and soil. The leak occurred at 74th Avenue S and S 259th Street in Kent. There were no further details on the volume or clean up with the WDOE files.

Trans Mountain Oil Pipe Line Corporation - On January, 15 1991, a natural gas condensate (a liquid petroleum product used in the production of gasoline) leak was detected by Trans Mountain at the Laurel Pump Station, located at 1009 East Smith Road, just north of Bellingham. Approximately 3,200 gallons leaked from an underground instrumentation line and released product to soils, surface waters, sediment and shallow groundwater. Some product flowed across a field and entered a stormwater system which drains into a tributary of Deer Creek. Trans Mountain's initial site assessment indicated elevated TPH and BTEX in the shallow aquifer just west of the pump station and elevated

TPH in soils to the west and northwest of the pump station. Due to presence of a continuous clay layer between the upper contaminated aquifer and the lower aquifer (used for drinking water supply), drinking water contamination did not occur. Remediation efforts, including removing product from the ground surface, stormwater system and surface water system, installing surface water and groundwater monitoring systems, landfarming soils, venting the soils and pumping and treating contaminated groundwater which continued at the site up until the 1998 site report on file at Ecology.

5.6 Overview of Remedial Technologies

Based on a brief review of the case histories above and on available EPA documentation, this section provides an overview the steps that would be required in the event that soil and/or groundwater contamination were detected as a result of a spill from the Cross Valley Pipeline.

The selection of a recommended action alternative is completed in the following four steps:

- Identification of clean up criteria;
- Screening of potential remedial technologies based on applicability to gasoline and diesel contamination and the ability of the technologies to meet the identified cleanup criteria;
- Evaluation of the suitable remedial technologies identified during the screening process; and,
- Ranking of the alternatives.

The remainder of this section will identify appropriate clean up criteria, discuss remedial technology alternatives and present approximate costs based on case studies for remediation of gasoline and diesel contaminated soil and groundwater.

5.6.1 Clean Up Criteria

In Washington State, site clean up is regulated by the Model Toxics Control Act or MTCA (WAC 173-340). MTCA Method A standards for hazardous substances are established at concentrations at least as stringent as concentrations specified in applicable state and federal laws. MTCA Method A levels are used for sites where the cleanup action is determined as "routine" or may involve relatively few hazardous substances (WAC 173-340-700). For gasoline and diesel spills, MTCA Method A standards are typically used. MTCA Method A criteria for published contaminants of concern in gasoline and diesel are listed below. For comparison and where available, EPA MCLs for groundwater are also shown. Method B standards may apply at complex sites requiring cleanup of several different and or hazardous contaminant types. Method C levels are applicable to sites where it may be impossible to achieve either Method A or B standards or where reaching Method A or B levels may cause greater

environmental harm (WAC 173-340-700). For soils, Method C levels can also be used for cleanup of industrial sites.

Hazardous Substance	EPA Groundwater MCLs (ug/L)	MTCA Method A Groundwater Clean Up Level (ug/L)	MTCA Method A Soil Clean Up Level (mg/kg)	WA State Drink Water Std (ug/L)
Benzene	5	5	0.5	1.0
Ethylbenzene	700	30	20	ns
Toluene	1,000	40	40	ns
Xylenes	10,000	20	20	ns
PAHSs (carcinogenic)	ns	0.1	1.0	0.01
Total Petroleum Hydrocarbons (TPH)	ns	1000		ns
TPH (gasoline)	ns		100	ns
TPH (diesel)	ns		200	ns
MTBE	ns	ns	ns	ns

Note: ns - no standards set.

Clean up levels for MTBE have not been established.

5.6.2 Remedial Alternatives

To identify appropriate technologies, the following sources were reviewed:

- Bouwer, E., Mercer, J., Kavanaugh, M. and DiGiano, F. (1988). Coping with groundwater contamination. Journal WPCF, Vol. 60, No. 8, pp. 1415-1427.
- EPA (1996). Pump and Treat Groundwater Remediation. United States Environmental Protection Agency, EPA/625/R-95/005, July 1996.
- EPA (1995a). Remediation Case Studies: Soil Vapor Extraction. United States Environmental Protection Agency, EPA/542/R-95/004, March 1995.
- EPA (1995b). Remediation Case Studies: Groundwater Treatment. United States Environmental Protection Agency, EPA/542/R-95/003, March 1995.
- EPA (1992). A Technology Assessment of Soil Vapor Extraction and Air Sparging. United States Environmental Protection Agency, EPA/600/R-92/173, September, 1992.
- EPA (1991). Guide for Conducting Treatability Studies under CERCLA: Soil Vapor Extraction. United States Environmental Protection Agency, EPA/540/2-91/019B, September 1991.
- Keller, A., Froines, J., Koshland, C., Reuter, J., Suffet, I. and Last, J. (1998). Health and Environmental Assessment of MTBE. Report to the

Governor and Legislature of the State of California. Vol. 1, Summary and Recommendations. November, 1998.

Based on Golder experience and the references cited above, the following technologies were identified as possible remedial alternatives:

- Soil Vapor Extraction (SVE)
- Air Sparging
- In-Situ Bioremediation
- Ex-Situ Bioremediation
- Groundwater Extraction and Treatment ("Pump-and-Treat")

Soil Vapor Extraction (SVE)

The SVE process is an in-situ technique for the removal of volatile organic compounds (VOCs) and some semi-volatile organic compounds (SVOCs) from the vadose zone. The process involves installation of vapor extraction wells in the contaminated zone. As air is removed from the soil through the wells, ambient air is injected or drawn through into the soil. When ambient air flows through the soil contaminants are volatilized and removed.

SVE is most effective at removing compounds which have a high vapor pressure and volatility (such as MTBE and BTEX) and is therefore highly effective for remediation of gasoline range petroleum hydrocarbons. However, due to the lower vapor pressure and volatility of the heavier diesel components (such as PAHs), SVE is less effective for remediation of diesel. The soil characteristics also have a significant effect on the applicability of SVE. In general SVE is more efficient in relatively dry soils with a high air permeability and low clay and organic carbon content.

Air Sparging

Air Sparging is a technology utilized to remove VOCs from the subsurface saturated zone. Air is introduced into an impacted aquifer system and contaminants transfer from subsurface soil and groundwater into sparged air bubbles. The air bubbles migrate into the unsaturated zone where they can be removed by SVE.

Air sparging usually operates in tandem with SVE systems. Without SVE, a net-positive subsurface pressure could cause contaminant migration to as-yet unaffected areas. Also, uncontrolled contaminated soil vapor could flow into buildings or utility conduits creating potential explosion or health hazards. As for SVE, air sparging is more effective to remove volatile, high vapor pressure compounds. However, since air sparging increases the oxygen content of the groundwater, it will also enhance in-situ aerobic biodegradation of petroleum constituents, irrespective of volatility.

The table below lists the factors which control the effectiveness of air sparging systems.

Air Sparging Control Factor	Favorable Conditions	Unfavorable Conditions
volatility of contaminants	high volatility	low volatility
solubility of contaminants	low solubility	high solubility
biodegradability	high biodegradability	low biodegradability
permeability	$> 10^{-3}$ cm/sec	$< 10^{-3}$ cm/sec
aquifer type	Unconfined	confined
soil type	sandy soils	clay, high organic soils
presence of LNAPL	none or thin layer	thick LNAPL layer
bedrock aquifer contamination	highly fractured bedrock	unfractured bedrock

In-Situ Bioremediation

This technology involves the use of microorganisms to degrade contaminants in groundwater and/or soil. Since most petroleum hydrocarbons are biodegradable, it is a suitable technology for reduction of BTEX and low molecular weight PAHs (including naphthalenes). High molecular weight PAHs (including CPAHs) are not readily biodegradable. However, since these compounds are: 1) at very low concentration in gasoline and diesel; 2) tend to stay in the NAPL rather than partition into water; and, 3) tend to sorb on to soils, they are not as great a threat to groundwater as the more mobile constituents. MTBE is also resistant to aerobic biodegradation. Due to its high mobility in the environment, an alternative technology would have to be used in conjunction with in-situ bioremediation if MTBE levels are of concern.

In order for biodegradation to occur, microorganisms require nutrients (e.g. nitrogen and phosphorus) and an electron acceptor (e.g. oxygen) and a substrate (the hydrocarbon contaminant). Several other conditions such as pH, temperature, contaminant concentration, solubility, volatility, viscosity and toxicity, redox conditions, aquifer permeability, and soil type also impact the effectiveness of the process.

In-situ bioremediation systems for aquifers typically consist of injection wells or infiltration galleries. These systems are often integrated with other technologies, for example air stripping which can be used to both physically reduce levels of volatile hydrocarbons as wells as provide oxygen for bioremediation (bioventing).

Ex-Situ Bioremediation

Ex-situ bioremediation involves excavating the contaminated soils and placing them in a favorable condition where microorganisms will use the hydrocarbon contaminants as a substrate. Two examples include land farming and aerating within a biopile. In land treatment, volatile compounds (for example, MTBE and BTEX) volatilize to the atmosphere as well as being biodegraded. In instances where this is not acceptable, treating in a biopile is advantageous since air can be drawn through the pile, collected and treated prior to release to the atmosphere.

Ex-situ bioremediation may also involve biological treatment of groundwater extracted using a pump-and-treat system. As an example, the contaminated groundwater may be passed through a bioreactor in which conditions favorable for biodegradation are engineered.

Groundwater Extraction and Treatment

“Pump-and-treat” methods involve pumping contaminated water to the surface for treatment. These systems are used to hydraulically contain contaminated groundwater by preventing continued expansion of the contaminated zone as well as reducing the dissolved contaminant concentrations. The effectiveness of a pump and treat system is dependent on well placement, pumping rates, aquifer heterogeneity, permeability and organic carbon content, desorption of the contaminant and contaminant solubility. Experience with this technology indicates that pumping for years or decades may be required to remove even weakly sorbing contaminants such as benzene (Bouwer et al., 1988). Pumped water can be treated at surface either by for example: 1) air stripping (for MTBE and BTEX); 2) by passing the water through granular activated carbon (GAC) which adsorbs the full range of petroleum hydrocarbons; and/or, 3) by passing the water through a bioreactor.

5.6.3 Approximate Remediation Costs

The costs associated with investigation and remediation are highly variable and site specific. Cost factors include the location of the site, the depth to groundwater, the extent of the vertical and horizontal migration of the groundwater plume, contaminant characteristics and the subsurface geology. The costs presented in the table below focus on costs incurred at a contaminated site and should therefore not be extrapolated directly to hypothetical remediation of the Cross Valley Aquifer if it were to be contaminated with gasoline and/or diesel. Significantly higher costs would result if treatment (air-stripper) was required at one or more of the CVWD wells. Instead, the values should be used to provide a range of possible costs which may be incurred in this event.

CVWD would probably incur a proportional cost in order to review clean-up strategies, monitor site activities, increase water quality monitoring, address customer concerns, and submit compliance reports.

Site Name	Compound s	Technology	Media Treat ed	Capita l Cost	Annual Op. Cost	Year s	Sourc e
Hill Air Force Base, UT	BTEX and TPH	SVE and bioventing	soil	599,000	132,000	2	1
Amcor Precast, UT	BTEX and TPH	air sparging & biodegradation	soil and gw	156,950	62,750	1.5	2
Ft. Drum, NY	BTEX and TPH	pump and treat	gw	958,780	129,440	>3	2
Langley AFB	BTEX and TPH	vacuum extraction	gw	569,739	190,000	>3	2

Sources: 1. EPA (1995a)
2. EPA (1995b)

Given the mobility and resistance to biodegradation of MTBE, investigation and remediation of MTBE will be required for most contaminated sites (Keller et al., 1998). Generalized estimates obtained from industry representatives for site investigations ranged from \$30,000 to \$250,000 for typical gasoline station sites with plumes ranging from 20 to 1,000 feet (Keller et al., 1998). These sites normally take 2 to 5 years to remediate based on typical BTEX and MTBE plumes. Using SVE to remediate, the average cost of remediation is \$4,500 per month or a total of \$108,000 to \$270,000. For pump and treat, assuming the typical leaking underground storage site has an MTBE concentration of 200 ug/L, remediation costs are likely to vary between \$140,000 to \$240,000. The cost of a similar benzene site, treated to 1 ug/L, would be approximately \$55,000 to \$180,000. Note that these costs assume that the remediation is being performed on relatively young MTBE plumes (Keller et al., 1998). Pipeline ruptures typically involve significantly larger volumes of gasoline than USTs at gasoline stations. Including site investigation costs, a pipeline spill may cost from \$750,000 to \$1,000,000 (Keller et al., 1998).

5.7 Spill Response Planning

This section outlines groundwater protection strategies appropriate for the CVWD to consider if the Cross Cascade Pipeline is constructed. Three "goals" should be considered in identifying a strategy that is applicable to protection of a sensitive groundwater supply: prevention, mitigation, and monitoring.

1. Prevention is defined as the actions that would prevent any contamination from entering the ground surface. Short of re-location of the pipeline alignment, preventative measures would typically be engineered designs applied to the pipeline itself or the trench in which it is placed. If the primary goal is prevention, a high level of reliability,

- accuracy, and redundancy is required in the pipeline itself. Highly reliable prevention can minimize the need for mitigation and monitoring.
2. Mitigation is defined as the actions that would mitigate, alleviate or minimize contamination that is released. Mitigation measures would typically be response actions and clean-up protocols that would be used in the event of a spill, and design elements that would complement the actions necessary in the event of a spill. If the primary goal is mitigation, a high level of reliability, accuracy, and redundancy is required in the systems surrounding the pipeline and the actions taken if a spill occurs.
 3. Monitoring is defined as the on-going system by which the performance of the prevention and mitigation goals is documented.

Based on the spill volumes presented in the DEIS, prevention, mitigation and monitoring should be considered for two levels of spill:

- An “undetectable” release that could persist for a period of days or weeks. This type of spill could release volumes on the order of 100 to 80,000 gallons. The release of product from OPC’s Renton-area pipeline apparently went undetected for nearly one year. The Renton spill was on the order of 80,000 gallons.
- A detectable release that could persist for a period of hours. This type of spill could release larger volumes, potentially in the 100,000 to 300,000 gallon range.

5.7.1 Prevention Strategies

The most obvious prevention strategy for protecting the CVWD aquifer would be an alternate alignment for the pipeline. There is some degree of prevention provided in the design, construction, and testing of the pipeline. Additional pipe wall thickness, localized cathodic protection, more detailed inspection and additional block valves would increase the reliability of the preventative elements of the pipeline, but may not completely prevent a release. Remote monitoring of pipeline flows (through the SCADA system) is not preventative, since detection of a release does not prevent it from occurring.

The volumes of product present in the pipeline at any given time are large enough that it is probably impossible to have a completely preventative design of the pipeline that protects the CVWD service area from large “detectable” releases. For “undetectable” releases, the closest thing to prevention would involve trench or vault designs that could accommodate an “undetectable” release without overflow or seepage into the ground. This type of design might include different trench geometry and/or bulkheads, placed based on topography and drainage patterns along the alignment or vaults for pipeline valves.

5.7.2 Conventional Mitigation Strategies

Mitigation strategies should be clearly specified in a spill response plan such that CVWD can accurately assess the reliability of the proposed response and clean-up. Mitigation is initially a function of response time to a detected release. Once a release is detected and a response is initiated, the methods used to characterize, clean-up, and monitor the site dictate the effectiveness of mitigation. OPC should identify characterization and clean-up approaches within the CVWD service area, taking into account site specific geotechnical conditions and a range of release scenarios. At a minimum, CVWD should ensure that it can review, comment and amend all spill response, site characterization and clean-up plans, and further review, comment, and amend based on new information as it becomes available.

Conventional mitigation strategies and response action alternatives are completed in the following four steps:

- Identification of clean up criteria;
- Screening of potential remedial technologies based on applicability to gasoline and diesel contamination and the ability of the technologies to meet the identified cleanup criteria;
- Evaluation of the suitable remedial technologies identified during the screening process; and,
- Ranking of the alternatives.

Clean-up criteria are provided in Washington State Model Toxics Act (MTCA). However, clean-up levels for drinking water are typically higher than MTCA standards. CVWD should specify drinking water standards as clean-up levels.

The following technologies are possible remedial alternatives that would be implemented at a release site:

- Soil Vapor Extraction (SVE)
- Air Sparging
- In-Situ Bioremediation
- Ex-Situ Bioremediation
- Groundwater Extraction and Treatment ("Pump-and-Treat")

CVWD should request that OPC conduct a screening level feasibility study of which technologies would be appropriate for different locations or spill scenarios within the CVWD service area. This may require some reconnaissance level of field investigation, such as test-pits or monitoring wells, and could be conducted during construction of the pipeline.

5.7.3 Alternate Mitigation Strategies

Three alternate approaches to mitigation are discussed below.

1.) Improved Leak Detection. For “detectable” releases, OPC appears to have adequate response capabilities. However, the fact that an “undetectable” release can occur, would suggest that one approach to mitigation would be to improve the ability to detect small releases. Improved detection could be accomplished by:

- *Vapor sensors:* Because vapors travel much faster than liquids in the subsurface, vapor sensors may detect leaks before major environmental damage occurs. Vapor systems are available to provide complete coverage of a pipeline and area able to be calibrated for specific subsurface conditions.
- *Other sensors:* Newer detection technology uses flexible, liquid absorbing cables to detect water, conductive liquids, and liquid hydrocarbon fuels and solvents in unwanted areas. When moisture is absorbed into the cable, the circuit shorts and current flow increases generating a spill alert. The instrumentation switches to a "locating" mode and provides the distance from the instrumentation to the spill location.
- *Pigging:* The most commonly used pipeline inspection tools (“pigs”) utilize the Magnetic Flux Leakage (MFL) technique in order to detect internal or external corrosion. The MFL inspection pig uses a circumferential array of MFL detectors embodying strong permanent magnets to magnetize the. Abnormalities in the pipe wall, such as corrosion pits, result in magnetic flux leakage near the pipe's surface. These leakage fluxes are detected by probes or induction coils moving with the MFL detector. Newer inspection tools (“smart pigs”) are shifting from the mere detection, location and classification of pipeline defects, to the accurate measurements of defect size and geometry. Modern, high-resolution MFL inspection tools are capable of giving very detailed signals, but requires considerable expertise, as well as a detailed understanding of the effects of inspection conditions and the magnetic behavior of the type of pipeline steel used.

2.) Redundant Water Supply: A second approach to mitigation would be to develop a redundant water supply system that is not susceptible to contamination from the pipeline and can meet the needs of the CVWD. This is more of a contingency than a mitigation. A hydrogeologic or engineering study would be necessary to identify possible alternate water supply (i.e. wells or interties) and the ability of those sources to meet CVWD needs. The system may need to be in-place prior to the occurrence of contamination in order to assure uninterrupted service.

3.) Treatment. A third approach to mitigation would be to provide water treatment for compounds found in gasoline, such as benzene and MTBE. A treatability and engineering design study is necessary to identify methods of treatment for the design flow rates and contaminant concentrations. The system may need to be in-place prior to the occurrence of contamination in order to assure uninterrupted service.

5.7.4 Monitoring Strategies

Additional monitoring should be initiated to ensure that groundwater quality standards are achieved and that a continuous water supply is assured for CVWD customers. The elements of the monitoring strategy should include:

Establishing compliance points. This basically defines the locations at which monitoring should occur (the monitoring network). Some combination of the CVWD production wells themselves, and off-site sentinel wells should serve as compliance points. The number and optimal placement of wells must be determined based on actual site characteristics and groundwater modeling. The design of the network should ensure reliable detection of relatively small contaminant plumes. This may require many wells.

Establishing action levels. This basically defines the contaminant level at which some action is taken for one or more monitoring locations. Typically, levels less than the MCL for a given contaminant are used as action levels in aquifers used as a drinking water supply. An action level essentially represents the community's "tolerance" for contamination.

Installing a monitoring system. For groundwater, we recommend both shallow and deep monitoring well completions. This would ensure that the vertical extent of possible contamination is identified.

Establishing background water quality levels. This can be accomplished using methodologies outlined in Ecology publication # 96-02, *Implementation Guidance for the Ground Water Quality Standards*.

Monitoring and reporting. Quarterly sampling is typical for environmental monitoring, and ensures that undetected, cumulative, or persistent contamination is identified.

5.7.5 Site Characterization

Adequate prevention, mitigation and monitoring strategies are dependent on accurate and defensible characterization of site conditions. We recommend that a comprehensive hydrogeological assessment of the pipeline alignment be carried out, utilizing guidance provided by Washington Department of Ecology. The site investigation should develop sufficient data to determine:

1. Geologic and hydrogeologic characteristics.
2. Ground water depth and flow direction, including seasonal variations.
3. Ground water velocity, transmissivity, storage coefficient, hydraulic conductivity, porosity, and dispersivity.
4. Thickness, permeability, and aerobic/anaerobic condition of the unsaturated zone.
5. Topography and drainage patterns.
6. Soil type, horizontal and vertical extent, infiltration rate, organic carbon content, and mineral content.
7. Location, construction, and use of existing wells within 1/4 mile of the alignment.

8. Background water quality, determined using methodologies outlined in Ecology publication # 96-02, *Implementation Guidance for the Ground Water Quality Standards*.

This information should then be used to conduct groundwater flow and transport modeling. The area impacted should take into account advection, dispersion, and diffusion of contaminants in ground water. The size of the area will depend upon the effluent quality, the aquifer characteristics, and the rate of assimilation. This modeling would be used to determine the optimal placement of monitoring devices, compliance points, and action levels to be used in a spill response and contingency plan.

6. CONCLUSIONS AND RECOMMENDATIONS

The general conclusion of our evaluation is that the applicant has insufficiently addressed the requirements of WAC 463-42-322, which requires that “The applicant shall provide detailed descriptions of the affected natural water environment, project impacts and mitigation measures and shall demonstrate that facility construction and/or operational discharges will be compatible with and meet state water quality standards”. Without substantial additional effort, Golder Associates cannot provide CVWD with a more detailed analysis of risk, potential contaminant pathways, and potential consequences to its water supply from the siting of the project. Therefore, in the absence of additional analysis, the CVWD must make the conservative assumption that their supply will be contaminated at some time in the future. This appears valid based on a preliminary assessment of risk, which suggests a spill probability of about 8×10^{-4} per year, or about 0.04 (1 chance in 25) over a 50-year period. Under present conditions, CVWD has no excess capacity and therefore an alternative source must be assured.

Detailed conclusions are summarized below.

6.1 Risk Methodology

- A detailed quantitative risk assessment would be a preferable method to “demonstrate that the facility is consistent with and will meet state water quality standards”.
- Performance measures can and should be specified for evaluating the impact of the project to the CVWD, or any groundwater user in a sensitive aquifer area. No performance measures are specified in the DEIS or application.
- For CVWD, performance measures should focus on groundwater quality, in terms of the likely concentration for contaminants of concern in proximity to the release site and at CVWD wells.
- Pipeline release scenarios can and should be specified that quantifies the probability of occurrence for various sections of the pipeline, based on its design and likely site conditions. A limited analysis of scenarios was prepared in the application, but the analysis is largely narrative and it does not categorize or quantify the likelihood of these scenarios.
- The consequences of a pipeline release are not identified to demonstrate the possible extent and magnitude of impacts, should a release occur. Quantification of consequences is necessary in order to assess risk.
- Defensible results from a risk assessment cannot be obtained without defensible data. The level of technical detail regarding groundwater and contaminant transport presented in the DEIS and application is insufficient to quantify risk in this manner.

- The data necessary for a risk assessment should be provided to the CVWD for their independent analysis of the risk to their water supply. Similar analyses may be appropriate for other sensitive aquifer areas.

6.2 Groundwater Protection Programs

Existing state groundwater protection programs are not utilized to the extent necessary for siting of a major facility that has the potential to contaminate groundwater, particularly when it is a sole source of drinking water for thousands of people. Specifically:

- The applicant does not reference or utilize guidance provided by the Washington Department of Ecology for implementing the Washington State Water Quality Standards. This guidance clearly outlines required site-specific elements of hydrogeologic and contaminant characterization for activities that could potentially contaminate groundwater.
- The applicant does not acknowledge that, as a Sole Source Aquifer, the EPA recommends that site specific hydrogeological assessments be considered with other project-related factors in evaluating a decision that could affect groundwater quality.
- The applicant does not acknowledge that the project will likely traverse Critical Aquifer Recharge Areas (CARA's), which are required to be designated by local jurisdictions as part of the Growth Management Act. When considering a "permit to locate over a designated CARA" Ecology provides detailed guidance and recommendations for the elements of a site evaluation, which are not acknowledged by the applicant.

6.3 Cross Valley Aquifer

- The hydrogeology of the Cross Valley Aquifer is not presented to the level of detail necessary to evaluate the potential pathways and consequences of a pipeline release along the proposed pipeline alignment. The application does not, therefore "provide detailed descriptions of the affected natural water environment". Additionally, a predictive analysis of the impacts from the construction and operation of the proposed pipeline has not been conducted. The application does not, therefore, "demonstrate that facility construction and/or operational discharges will be compatible with state water quality standards."
- Numerous wells exist along the pipeline alignment, but have not been identified or referenced with regard to location, stratigraphy or hydraulic properties. There are likely additional wells that are not on file with Ecology. All wells provide a potential conduit for contaminants to enter the main production zone of the Cross Valley Aquifer.
- The geologic stratigraphy, extent and hydraulic properties of near-surface geologic strata, and water-levels/flow directions in both shallow and production zones of the Cross-Valley aquifer are not presented and may be uncertain.

- Geologic descriptions of the till, which is thought to provide a barrier to contaminant migration, suggest appreciable proportions of sand and gravel, which could lessen its significance as a barrier.
- The CVWD is in the process of completing its Wellhead Protection Plan, and may collect additional data and conduct further analyses of the Cross Valley Sole Source Aquifer. Any further information developed by either CVWD or the applicant should be shared between parties and presented in a supplemental EIS for the project.

6.4 Contaminant Issues

A predictive analysis of the impacts from the construction and operation of the proposed pipeline has not been conducted. The application does not, therefore, “*demonstrate* that facility construction and/or operational discharges will be compatible with state water quality standards”. No estimate of groundwater contaminant concentrations are presented in either the DEIS or the application, though clearly, should a release occur, some impact to groundwater is likely.

- Contaminant migration in groundwater is complex and site-specific, and generally requires some sort of numerical model to demonstrate or predict impacts. No such prediction is provided in the DEIS or application.
- Gasoline and diesel products are complex and hazardous, and known to pose a threat to human health. New research on a gasoline additive (MTBE) is revealing potential health and environmental concerns. The behavior of MTBE in the environment is considerably more complex and long-lived than other gasoline components. The potential for future additives in gasoline, and their potentially unknown health and environmental effects is a valid concern for groundwater users along the pipeline alignment.
- It is recognized that the amount of a pipeline release will not correspond to the amount of product entering the groundwater system, and that a number of attenuation mechanisms exist for some gasoline contaminants. However, the documented persistence of MTBE in the environment and the documented persistence of groundwater contamination (since 1986) resulting from an OPC pipeline spill in Renton would suggest that more attention to contaminant transport is warranted in the permitting stage of this project.
- Remedial technologies available to OPC (and CVWD), should a spill occur, may have limitations at the release site due to till soils, or at a CVWD well, due to high flow rates. A comprehensive analysis of remedial actions, including the potential actions should a drinking water supply be contaminated, is not presented in the DEIS or application. Given that thousands of people rely on groundwater as their only drinking water supply, including the 20,000 customers of CVWD, more detail on remedial actions is warranted.

6.5 Spill Response Planning

Cross Valley Water District (CVWD) should develop mitigation and contingency plans, either independently or in conjunction with plans developed by Olympic Pipeline Company (OPC) that reflect the site specific and operational aspects of the CVWD service area. Given the lack of detail provided by OPC on these issues in its permit application and subsequently in the Draft Environmental Impact Statement, CVWD should request that OPC develop a spill prevention, mitigation and monitoring plan specifically for the Cross Valley Aquifer. The plan should clearly identify actions and contingencies, as well as how and when they will be implemented. OPC should work closely with CVWD on this plan, and should provide additional site-specific data in order to support the selection of specific actions. Preparation of the plan and concurrence by CVWD should be a part of any stipulated agreement with OPC.

In addition to its participation in developing a spill response plan, CVWD should initiate additional monitoring of its own wells, and possibly install additional monitoring wells to ensure that water quality standards are achieved and that a continuous water supply is assured for its customers. Based on the information provided by OPC in its application, it is our opinion that OPC should obtain significant guidance and oversight from CVWD in the design and implementation of a mitigation and monitoring strategy for a regionally significant sole-source aquifer. The City of Renton is developing, at OPC's expense, a protection plan for its aquifer areas that is traversed by an OPC pipeline. This approach may be applicable to CVWD.

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TABLES

FIGURES

PLATES

APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

APPENDIX E

APPENDIX F